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*Stennis Space Center*

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**Welcome  
to the  
NASA John C. Stennis Space Center  
Propulsion Test  
Customer Day 2002**



# Tuesday Morning Agenda

*Stennis Space Center*

- Agenda/Logistics Gary Taylor/Propulsion Test Directorate
- Welcome/Opening Comments Mark Craig/Deputy Director, Stennis Space Center
- Stennis Space Center (SSC) Video Tape
- SSC Overview Robert Lightfoot/Director, Propulsion Test Directorate
- Overview of A/B Test Complex Gary Taylor/Propulsion Test Directorate
- Overview of E Complex Bartt Hebert/Propulsion Test Directorate
- Overview of Test Support Services Stan Gill/Propulsion Test Directorate
- Engineering and Test Technology Shamim Rahman/Propulsion Test Directorate
- Rocket Propulsion Test Management Board (RPTMB) Mike Dawson/Manager, Propulsion Test Program Office



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# John C. Stennis Space Center

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## Unique Environment

- 30 Federal and State Agencies for Synergy and Cost-Sharing
- Government Managed, Contractor Operated
- DoD/NASA Working Relationship
- Commercial Customer Experience from Propulsion Test and Remote Sensing

## Proven Capability

- Business Systems, Service Providers and Infrastructure in Place
- Experienced Work Force
- 125,000 Acre Buffer Zone
- Environmental Relationship with State

## Strong Community Support

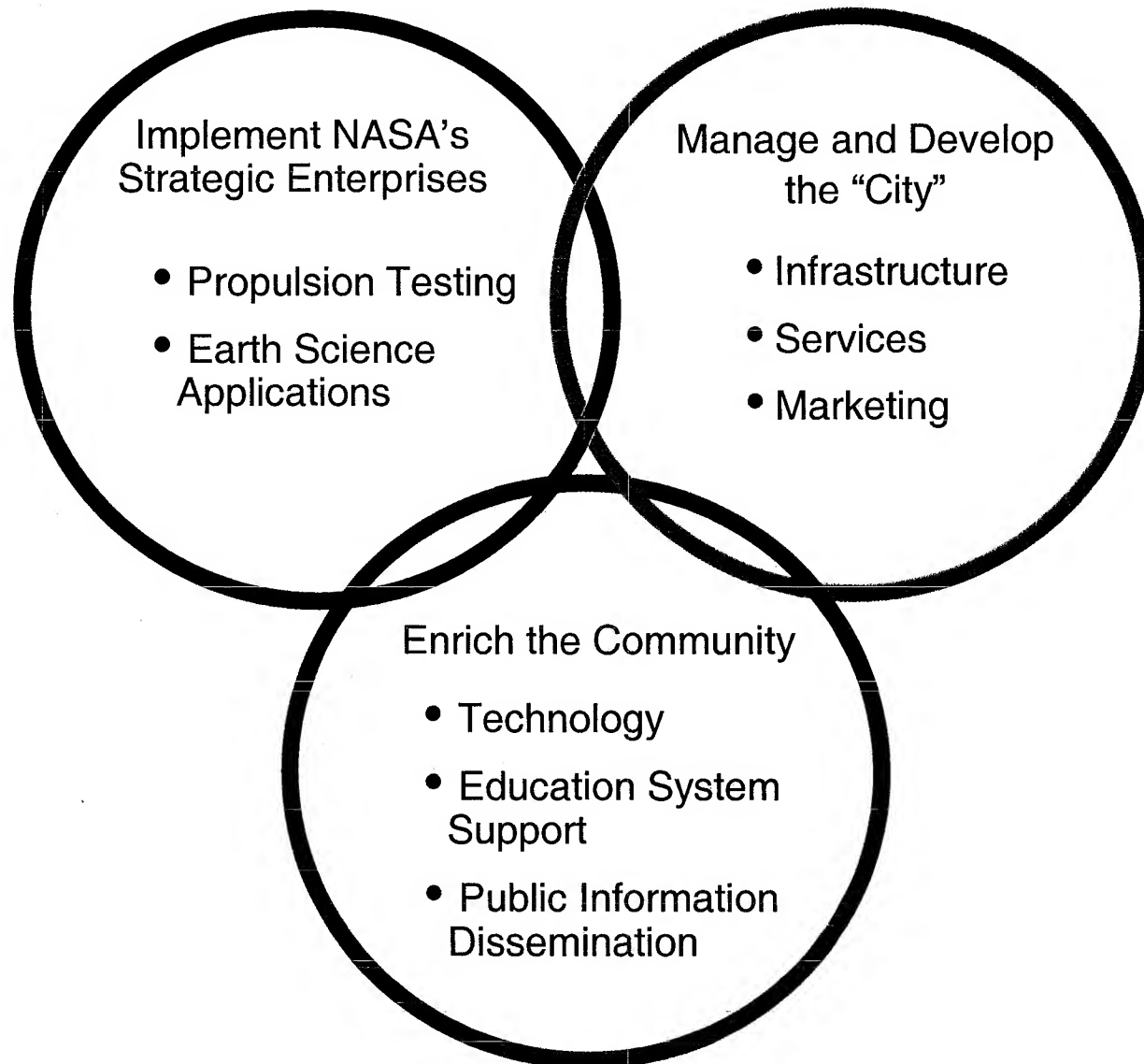
- A Recognized Contributor to Two States' Well Being
- Mississippi and Louisiana State Agency Presence on Site
- "Partners for Stennis" Local Support





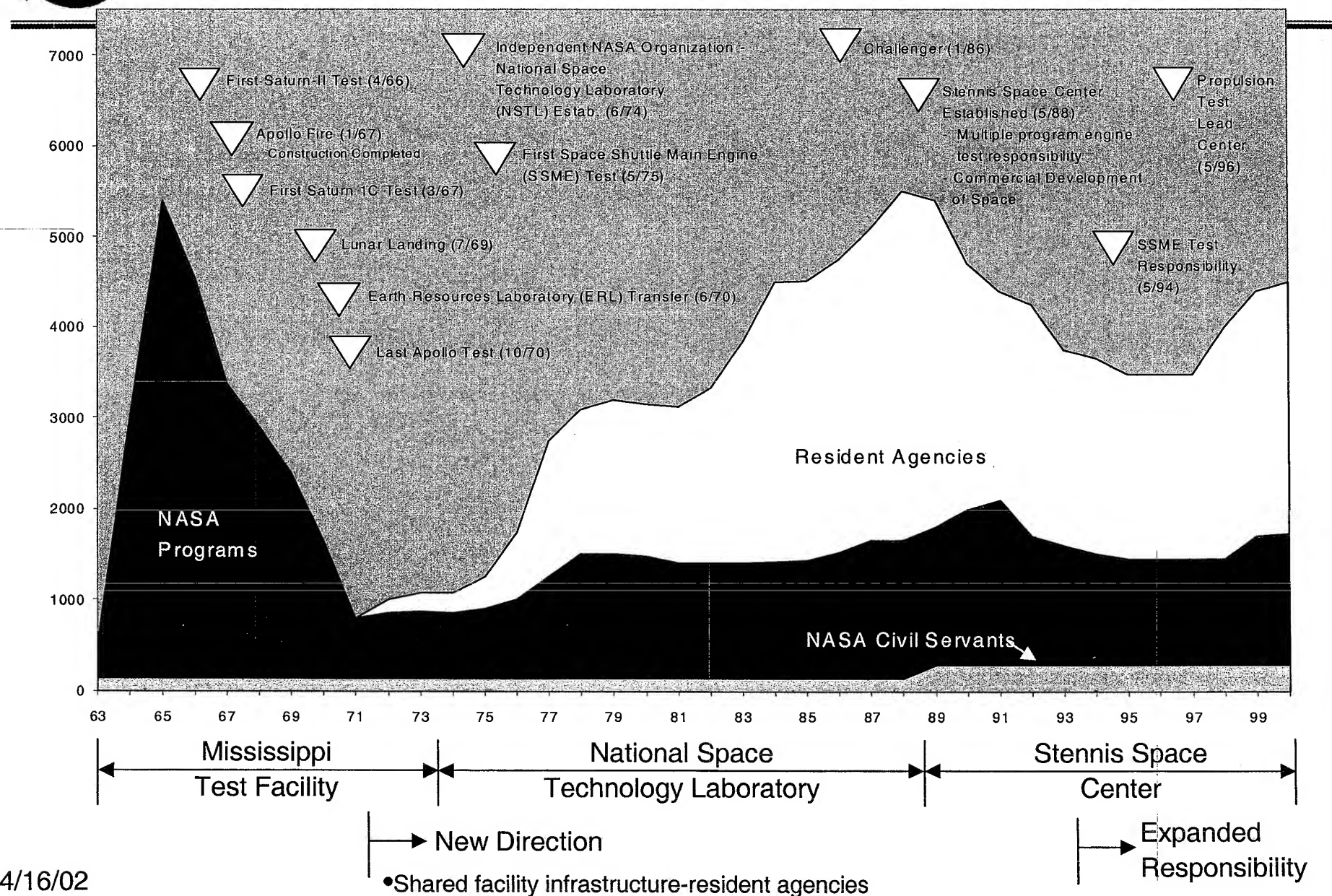
# NASA Activity at Stennis

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# Stennis Space Center Workforce/History





# Stennis Space Center Workforce

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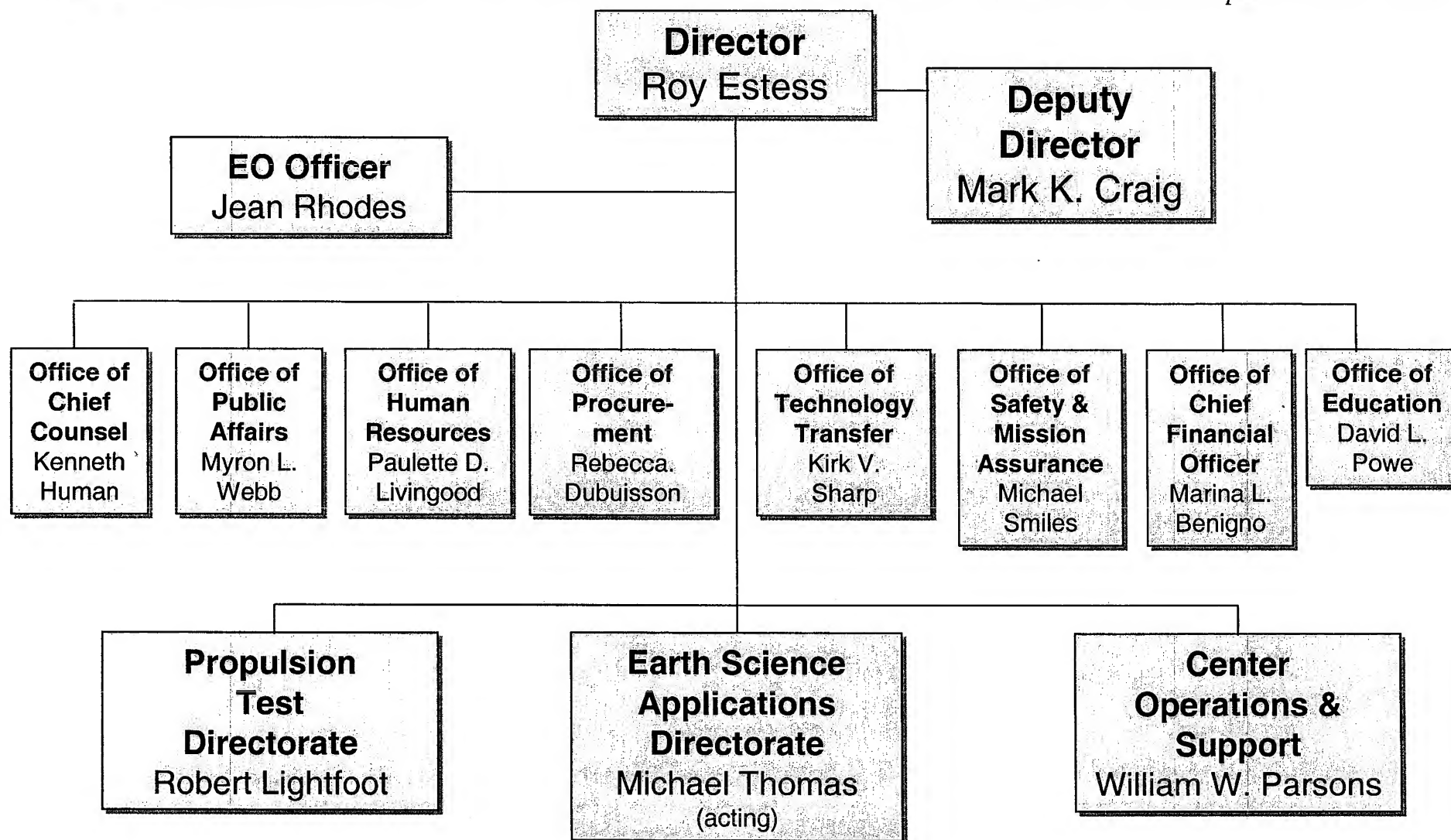
## 2001 Workforce at John C. Stennis Space Center

|                                          |       |
|------------------------------------------|-------|
| • NASA and Contractors                   | 1,730 |
| – SSC Federal Civil Servants             | 287   |
| – Contractor and Other                   | 1,443 |
| • Department of Defense and Contractors  | 1,279 |
| – Department of Navy                     | 1,205 |
| – Department of Army                     | 74    |
| • Department of Commerce and Contractors | 180   |
| • Other Resident Agencies                | 1,311 |
| Total                                    | 4,500 |



# Stennis Space Center Senior Management

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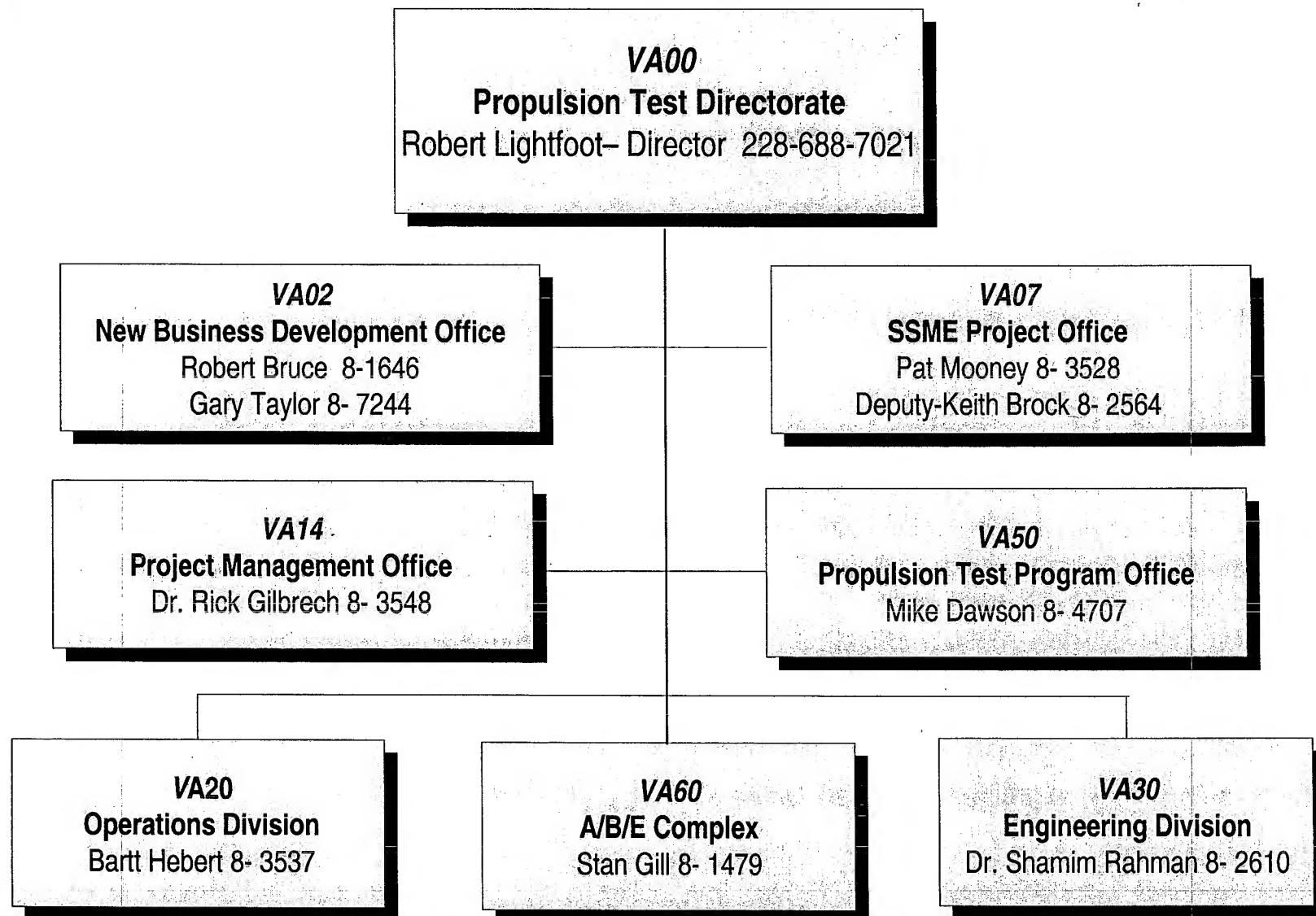




# Propulsion Test Directorate

## NASA John C. Stennis Space Center

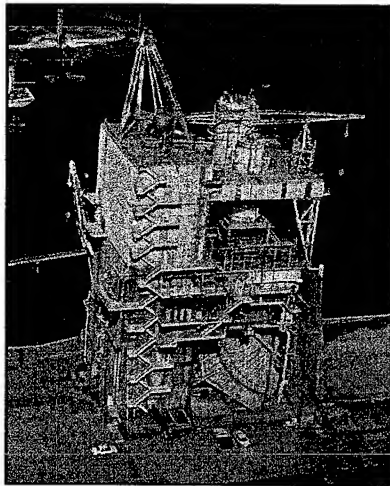
*Stennis Space Center*



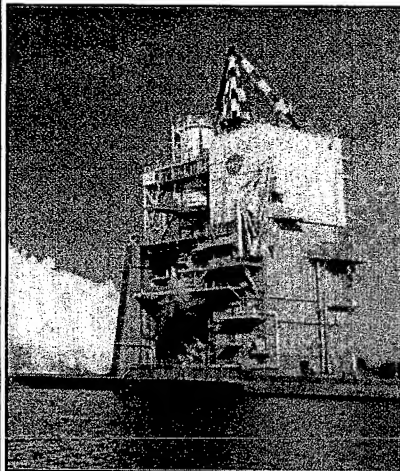


# SSC Test Stands

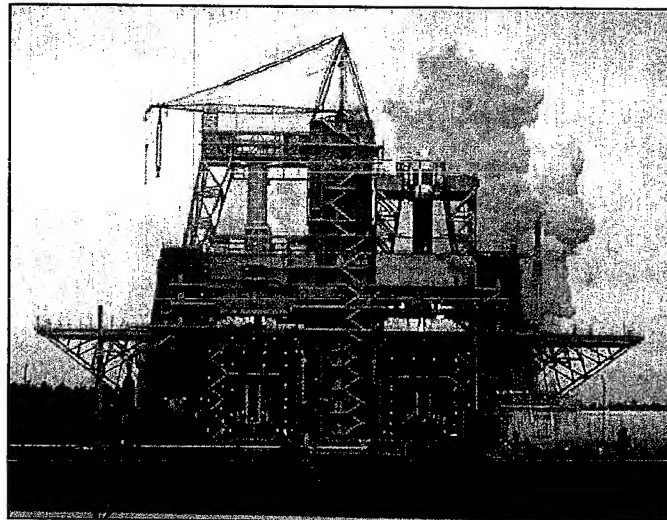
Stennis Space Center



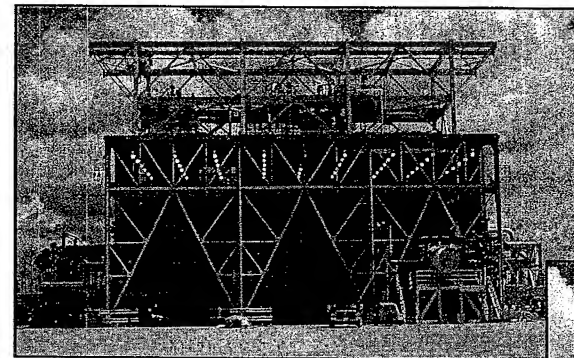
A-1



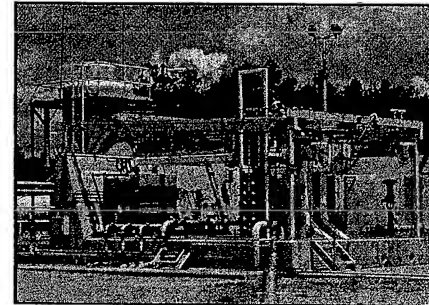
A-2



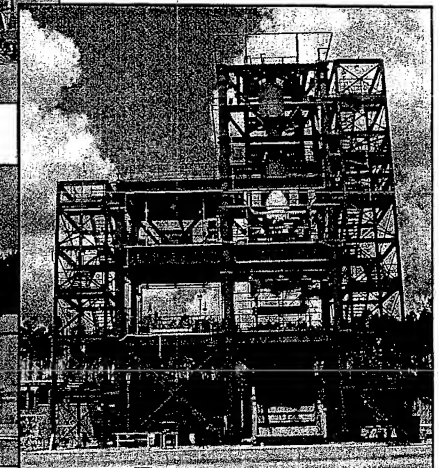
B-1/B-2



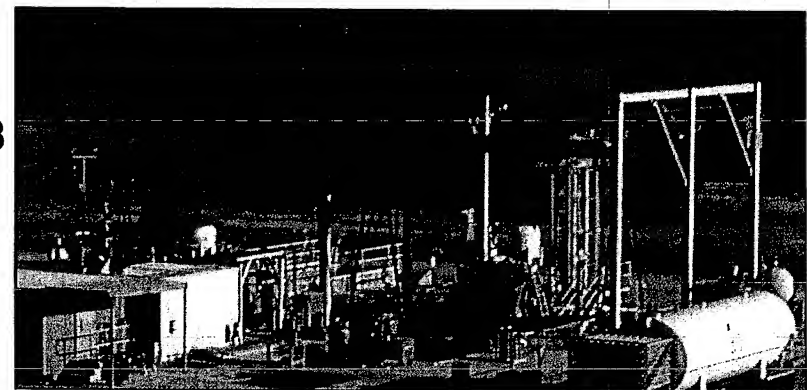
E-1



E-2



E-3







# Test Stand Utilization Schedule

CALENDAR YEARS

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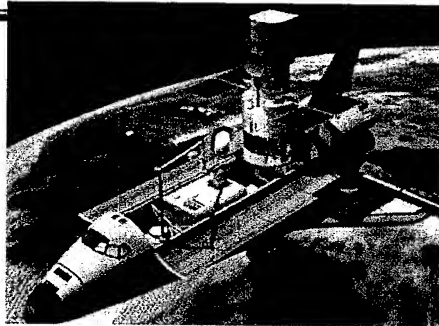
| TEST FACILITY | 01                 |            |                |   | 02                     |   |                |   | 03             |   |   |   | 04 |   |   |   | 05 |   |   |   |
|---------------|--------------------|------------|----------------|---|------------------------|---|----------------|---|----------------|---|---|---|----|---|---|---|----|---|---|---|
|               | 1                  | 2          | 3              | 4 | 1                      | 2 | 3              | 4 | 1              | 2 | 3 | 4 | 1  | 2 | 3 | 4 | 1  | 2 | 3 | 4 |
| A1            | X-33               |            | Maint          |   | SSME                   |   | Active Standby |   |                |   |   |   |    |   |   |   |    |   |   |   |
| A2            | SSME               |            |                |   | Maint                  |   |                |   | SSME           |   |   |   |    |   |   |   |    |   |   |   |
| B1            | PS-63              |            |                |   |                        |   |                |   |                |   |   |   |    |   |   |   |    |   |   |   |
| B2            | CBC                | Mothballed |                |   |                        |   |                |   |                |   |   |   |    |   |   |   |    |   |   |   |
| E1 Cell 1     | 250K Hybrid        |            |                |   | 33                     |   | COBRA PB       |   | Active Standby |   |   |   |    |   |   |   |    |   |   |   |
| Cell 2        |                    |            |                |   | IPD-LH2 PB/TP          |   |                |   | Active Standby |   |   |   |    |   |   |   |    |   |   |   |
| Cell 3        | IPD-LOX Turbo Pump |            |                |   | IPD Integrated Systems |   |                |   | Active Standby |   |   |   |    |   |   |   |    |   |   |   |
| E2 Cell 1     | LMA PLUS           |            |                |   | 33                     |   | Active Standby |   |                |   |   |   |    |   |   |   |    |   |   |   |
| Cell 2        | 5                  |            | Active Standby |   | USFE                   |   | Active Standby |   |                |   |   |   |    |   |   |   |    |   |   |   |
| E3 Cell 1     | HYSR               |            |                |   | MK-57 TPA              |   | Active Standby |   |                |   |   |   |    |   |   |   |    |   |   |   |
| Cell 2        | MR CB II           |            | MR CB III      |   | MR CB III              |   | Active Standby |   |                |   |   |   |    |   |   |   |    |   |   |   |

Occupied
  Project Pending
  Available
  Construction/Activation



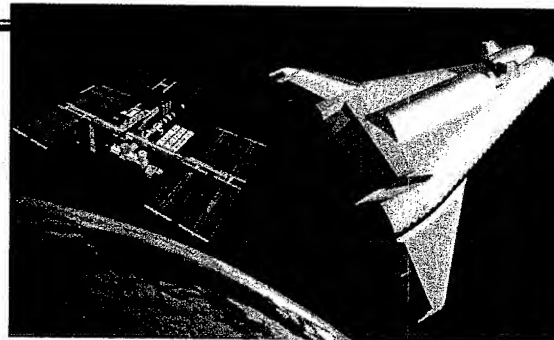
# NASA Programs

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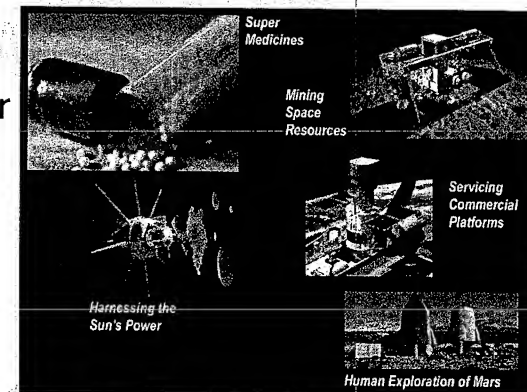
## Today: Space Shuttle 1st Generation RLV

- ◆ Orbital Scientific Platform
- ◆ Satellite Retrieval and Repair
- ◆ Satellite Deployment



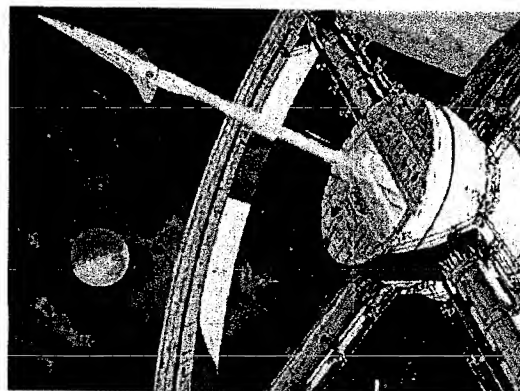
## 2010: 2nd Generation RLV

- ◆ Space Transportation
- ◆ Rendezvous, Docking, Crew Transfer
- ◆ Other on-orbit operations
- ◆ ISS, Orbital Scientific Platform
- ◆ 10x Cheaper
- ◆ 100x Safer



## 2040: 4th Generation RLV

- ◆ Routine Passenger Space Travel
- ◆ 1,000x Cheaper
- ◆ 20,000x Safer



## 2025: 3rd Generation RLV

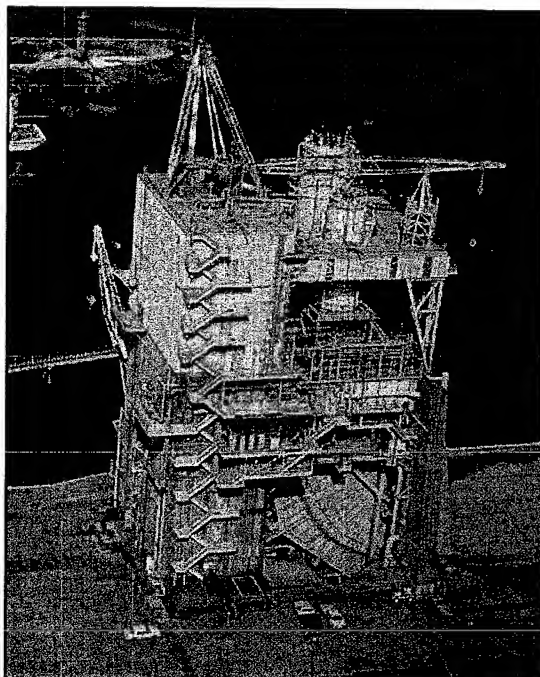
- ◆ New Markets Enabled
- ◆ Multiple Platforms / Destinations
- ◆ 100x Cheaper
- ◆ 10,000x Safer



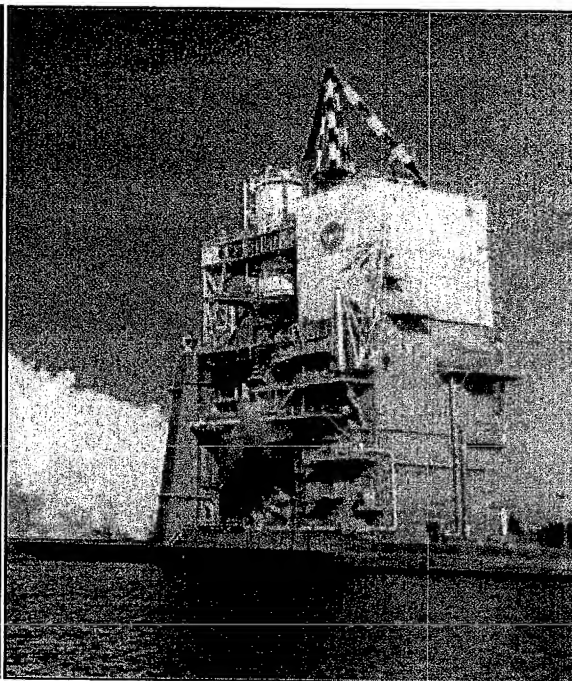


# A and B Test Complexes

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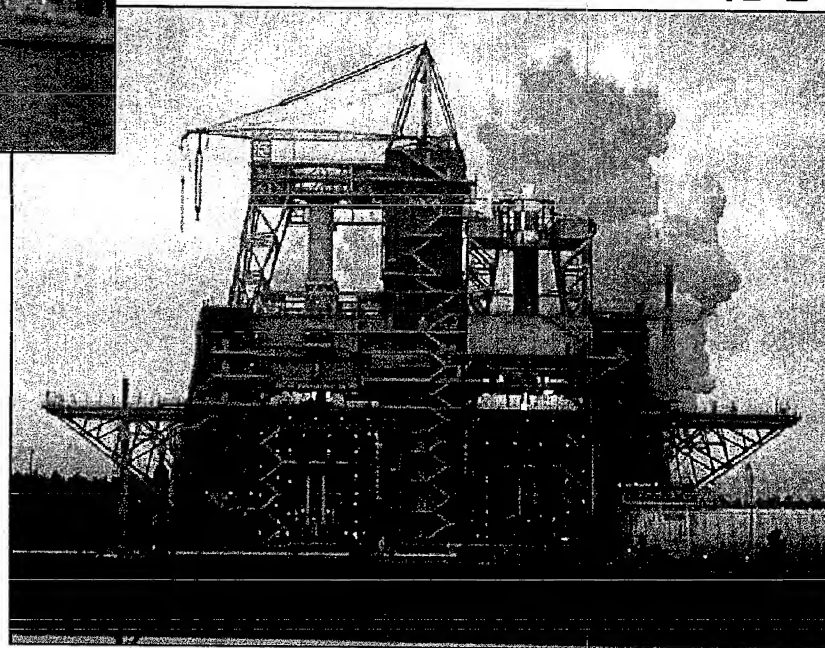
**A-1**



**A-2**

**Gary O. Taylor**  
**Propulsion Test Directorate**  
**NASA, Stennis Space Center**

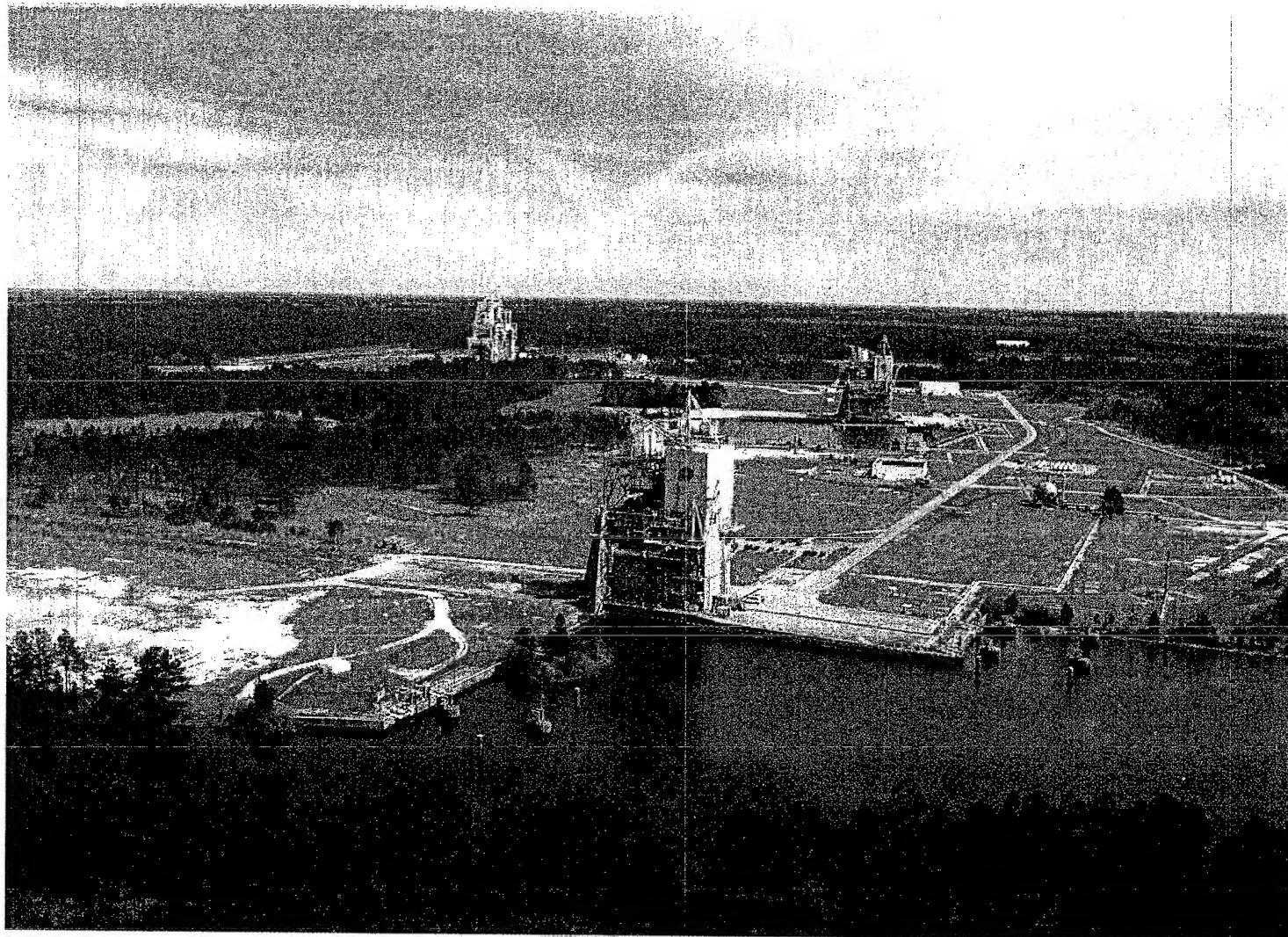
**B-1/B-2**





# A and B Test Complex

*Stennis Space Center*



4/16/02



# History of A/B Complex

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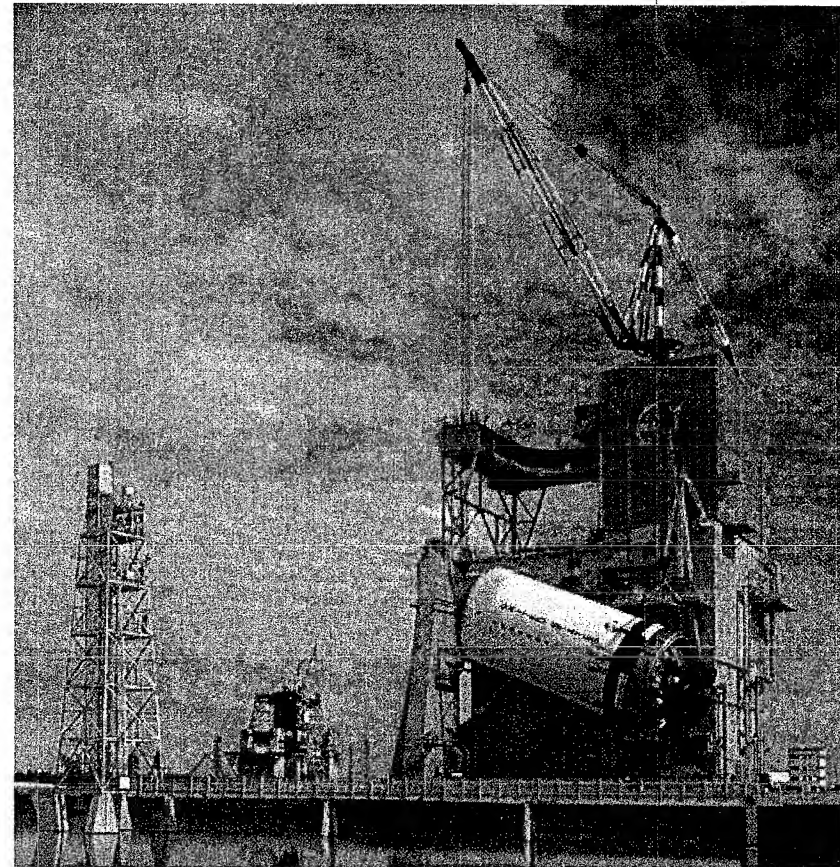
- Early 1960s – Early 1970s
  - National Rocket Testing Center
  - Support Flight Certification of 1<sup>st</sup> and 2<sup>nd</sup> stages of the Saturn V “Moon Rocket”
- Mid 1970s – Present
  - Support Space Shuttle Main Engine (SSME) development and certification test
  - Sea level, simulated altitude, and main propulsion cluster system (MPTA)
- Mid 1990s – Present
  - Continue SSME development and flight certification testing
  - Support government/government, agency/agency, and commercial programs
    - X-33 Program: Aerospike Engine Testing
    - NASA Research: MC-1 Engine/Assembly Testing
    - Commercial: RS-68 Engine/Stage Testing



# History of A Complex (A-1 & A-2)

*Stennis Space Center*

- Apollo Saturn V:
  - Second Stage (S-II) Testing
  - First Stage Test in April 1966
  - Stage:
    - Five J-2 engines
    - 1.15 M-lb thrust at altitude
    - LOX/LH<sub>2</sub>
    - 15 acceptance tests
    - 27 total static firings

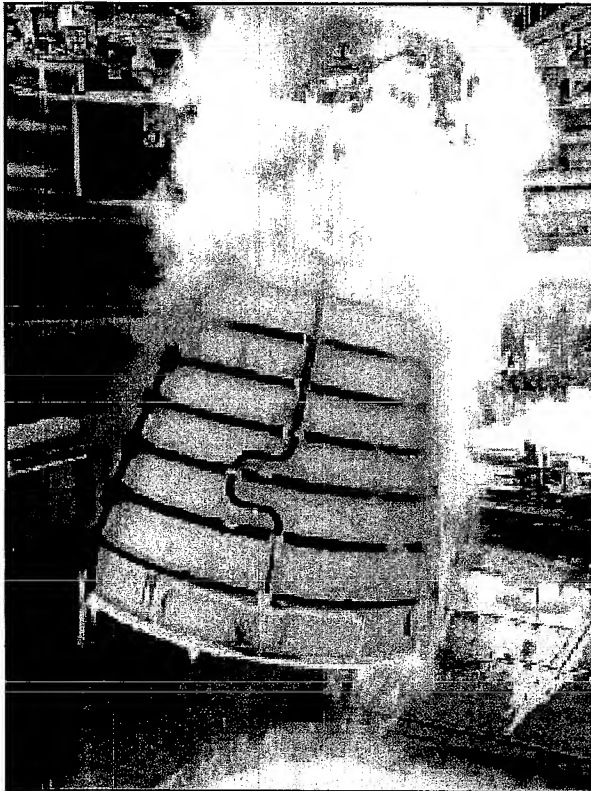


**Saturn V Second Stage is Lifted Into  
The A-2 Test Stand**



# History of A Complex (A-1 & A-2)

*Stennis Space Center*



- Space Shuttle Main Engine (SSME):
  - Single engine testing
  - Sea level and simulated altitude test
  - First static firing in May 1975
  - SSME:
    - 375 K-lb thrust at sea-level (100% RPL)
    - LOX/LH

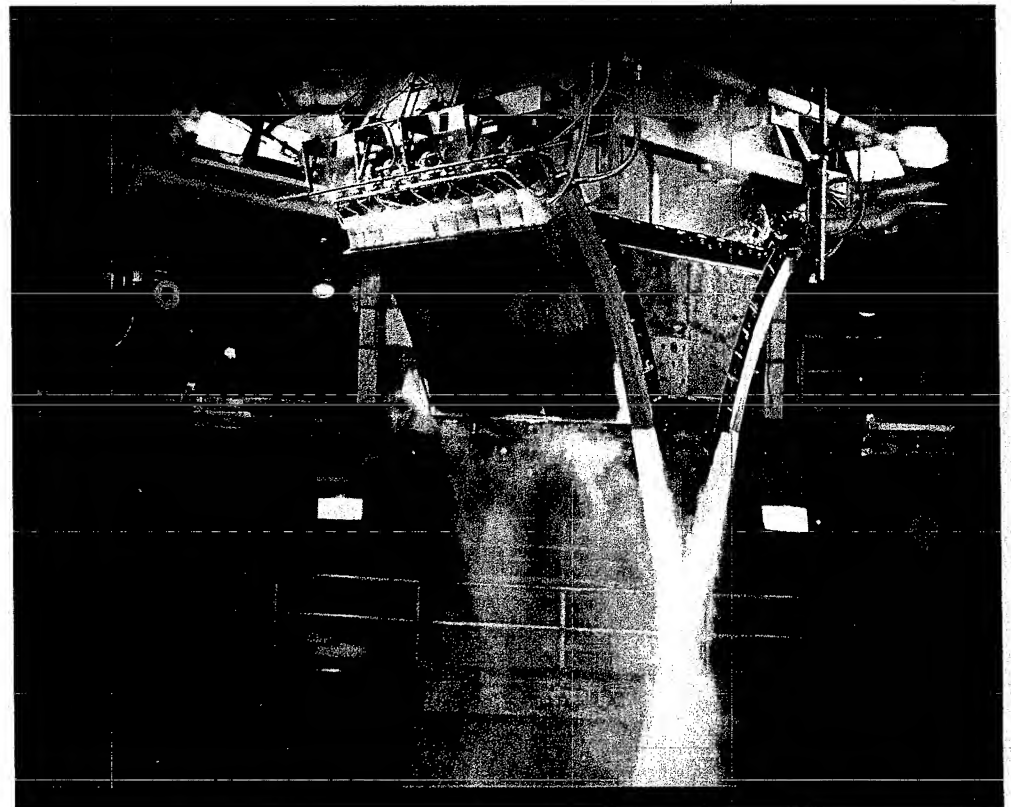




# History of A Complex (A-1 & A-2)

*Stennis Space Center*

- X-33/RLV Program
  - Linear Aerospike Engine Test
  - Testing initiated in 1998
  - Powerpack testing
  - Single and dual engine test
  - Completion in 2001
  - Engine:
    - 250K thrust
    - LOX/LH

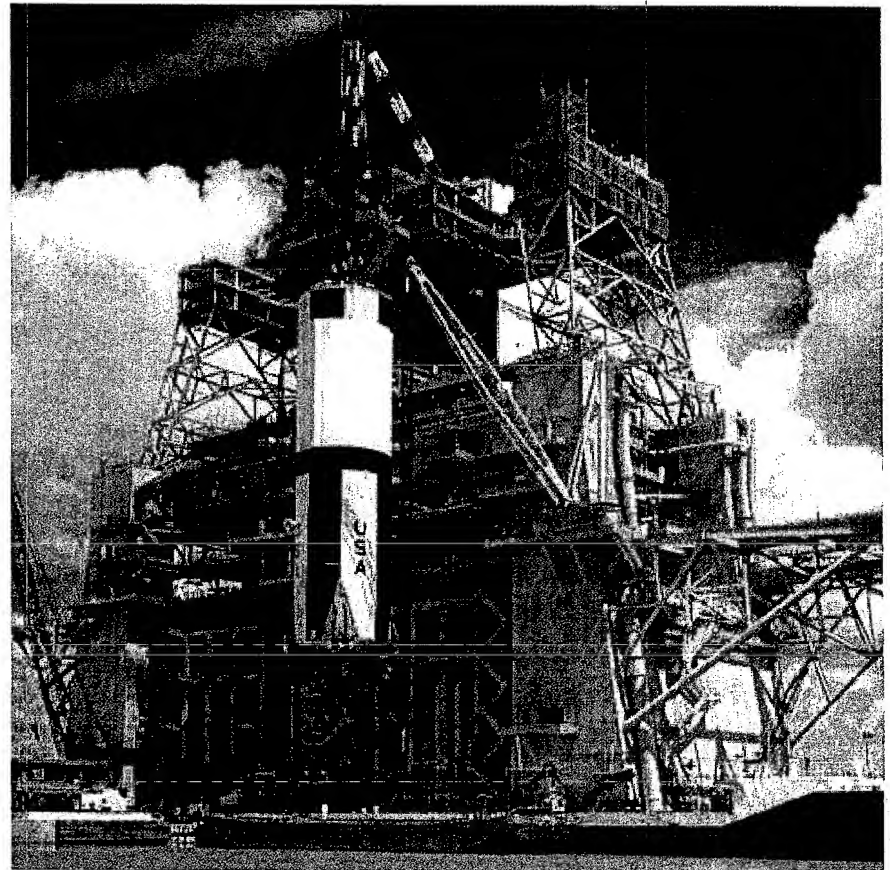




# History of B Complex (B-1 & B-2)

*Stennis Space Center*

- Apollo Saturn V:
  - 1<sup>st</sup> Stage (S-IC) Testing
  - First stage test in March 1967
  - Utilized the B-2 test position
  - Stage:
    - Five F-1 Engines
    - 7.5 M-lb thrust at sea level
    - RP-1/LOX
    - 15 total static firings



**Saturn V First Stage is Lifted Into B-2 Test Stand**

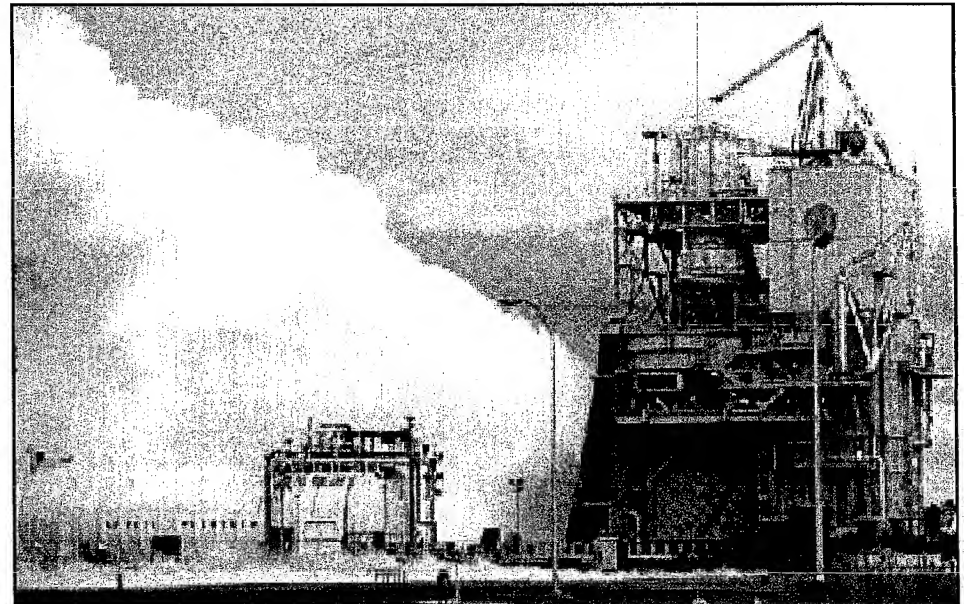




# History of B Complex (B-1 & B-2)

*Stennis Space Center*

- Space Shuttle Main Engine (SSME):
  - Single engine / Altitude simulated test
  - Utilized the B-1 test position
- Main Propulsion Test Article in B-2
  - 3 SSMEs
  - April 1978 through January 1981
  - 1.125 M-lb thrust at sea level
  - 18 total static test firing





# History of B Complex (B-1 & B-2)

*Stennis Space Center*

- MC-1 (Fastrac Engine):
  - Low Cost Booster R & D
  - X-34 Technology Demonstrator Program
  - First test Dec. 1998 (B-2 upper deck)
  - Continued testing through Oct. 1999
  - Engine:
    - 60K Thrust
    - LOX/RP-1

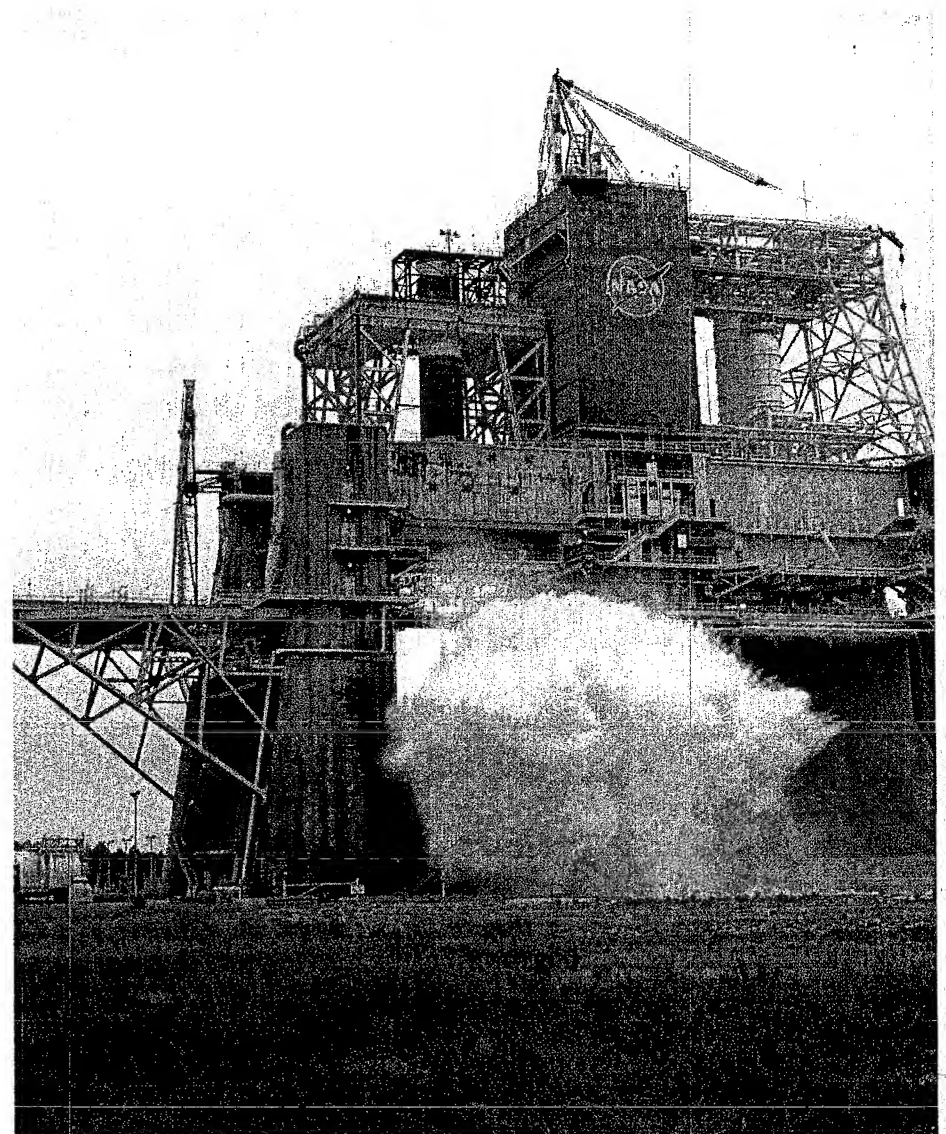




# History of B Complex (B-1 & B-2)

*Stennis Space Center*

- Combined Booster Core:
  - Delta IV Program
  - RS-68 Engine
    - 650K thrust
    - LOX/LH<sub>2</sub>

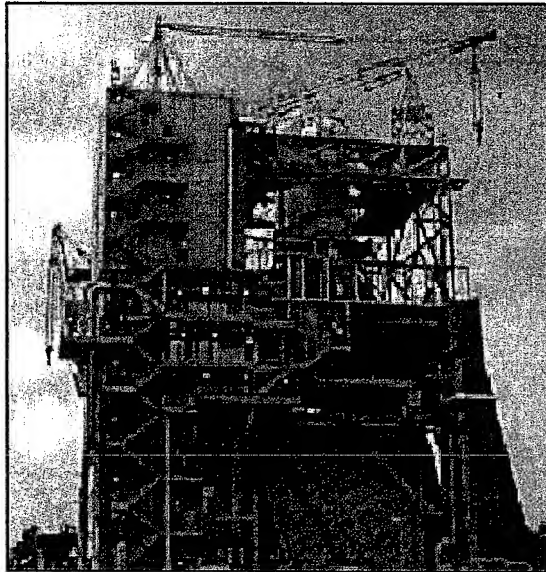




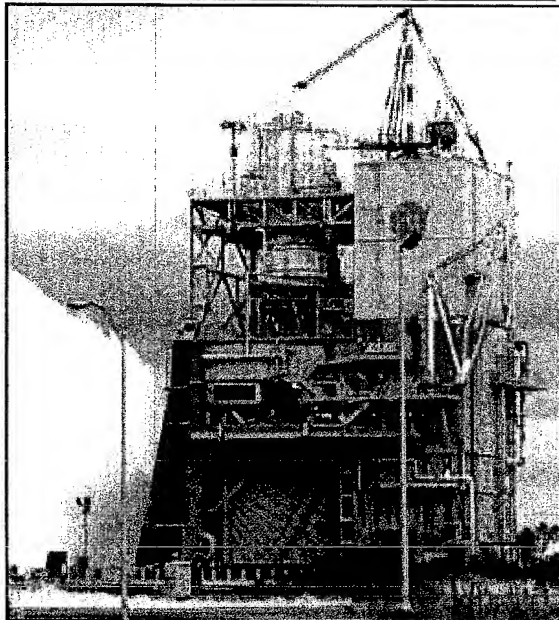
# A Complex Capabilities

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A-1



A-2



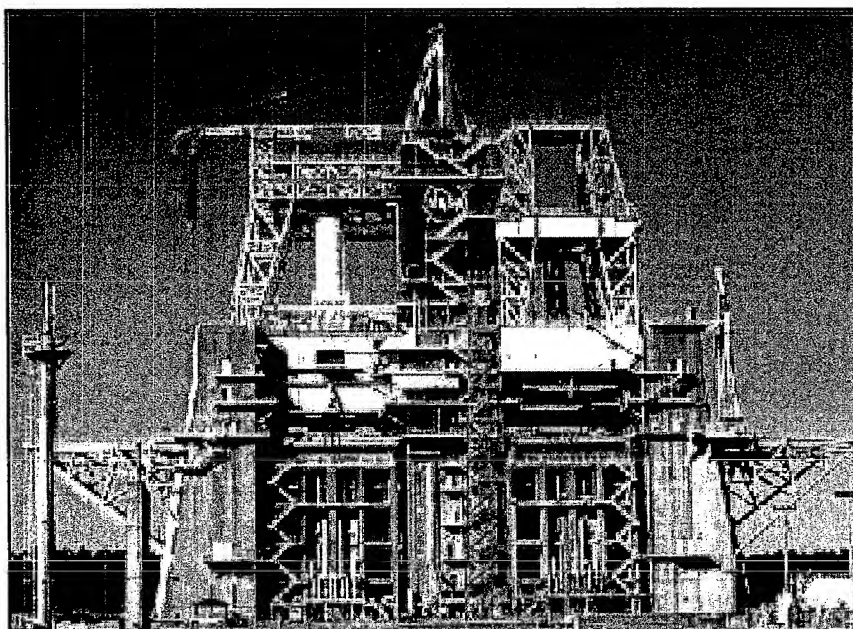
- A-1 & A-2 test stands similar in design
- Gimbal capability at A-1 (Sea level testing)
- Diffuser at A-2 (Simulated altitude testing)
- Designed for maximum dynamic load of 1.1 M lb thrust
- Supported by a dual capability test control center (TCC)
- Propellant run tanks
  - LH<sub>2</sub>: Water volume of 110K gallons, certified pressure of 50 psig
  - LO<sub>2</sub>: Water volume of 40K gallons, certified pressure of 250 psig
- Propellant barge docking stations
  - LH<sub>2</sub>: two (2)
  - LO<sub>2</sub>: two (2)



# B Complex Capabilities

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## B-1/B-2



- B-1/B-2 is a dual-position test stand
- Sea level and simulated altitude testing
- Designed for maximum dynamic load of 11 M-lb thrust
- Shared Test Control Center (TCC)
- Propellant run tanks
  - LH<sub>2</sub>: Water volume of 90K gallons, certified pressure of 66 psig
  - LO<sub>2</sub>: Water volume of 49.5K gallons, certified pressure of 110 psig
- Propellant barge docking stations
  - LH<sub>2</sub>: three (3)
  - LO<sub>2</sub>: three (3)



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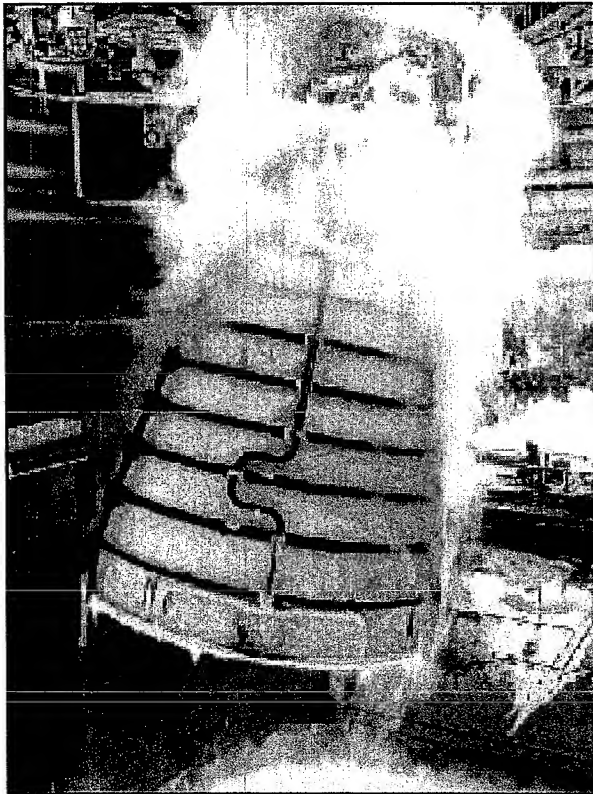
# Current Programs at A/B Complex



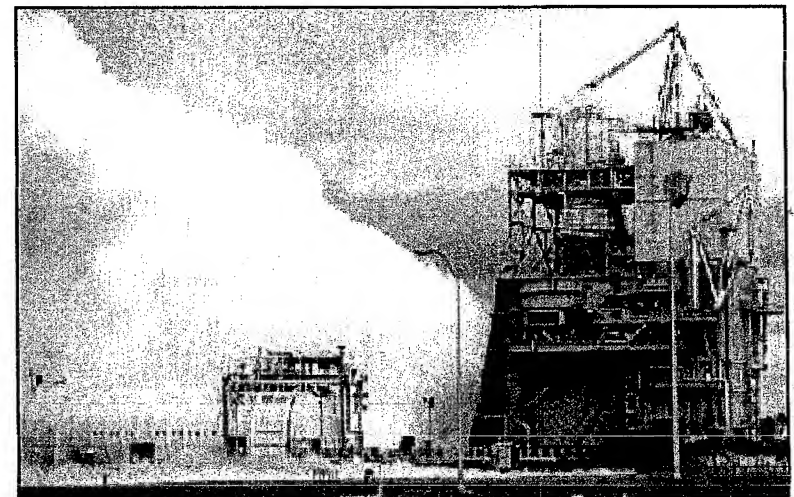


# Space Shuttle Main Engine

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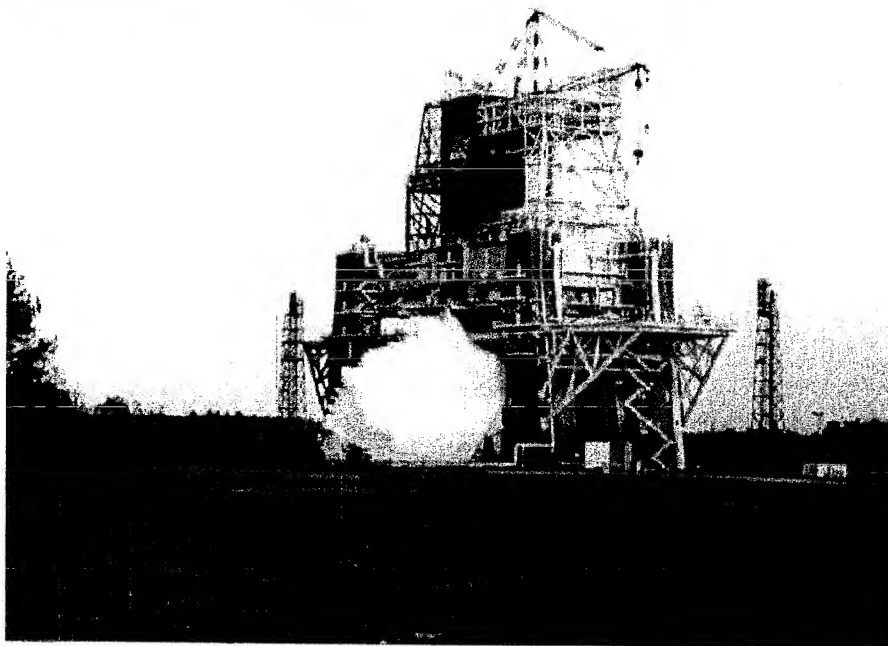
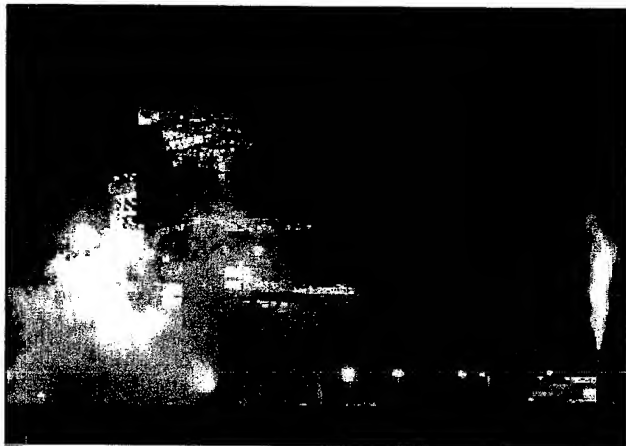
- Location
  - Transitioning to A-1 during A-2 modifications
- Scope
  - Acceptance Testing for Flight Program
  - Demonstrated Reliability Testing for Block II Engines
  - Anomaly Resolution
  - Engine Assembly/Maintenance
- Status
  - Engine installation into A-1
  - A-2 maintenance/modifications





# RS-68

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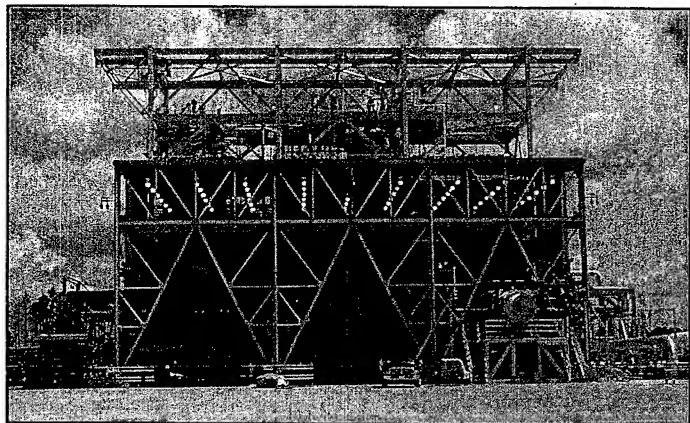


- Location
  - B-1 Test Position
- Scope
  - Development, Certification and Production Acceptance Testing
  - World-Class Assembly Facility at SSC
  - Two-position Test Stand
- Status
  - B-1 Dual Position Operational
  - 1st test on Position "B" - 9/8/99
  - 1st test on Position "A" - 11/6/99
  - 74 tests to date
  - Engine installation into position B in work



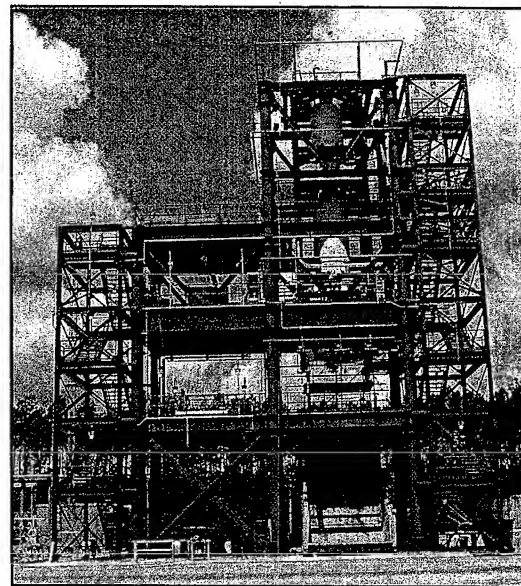
# E-Complex

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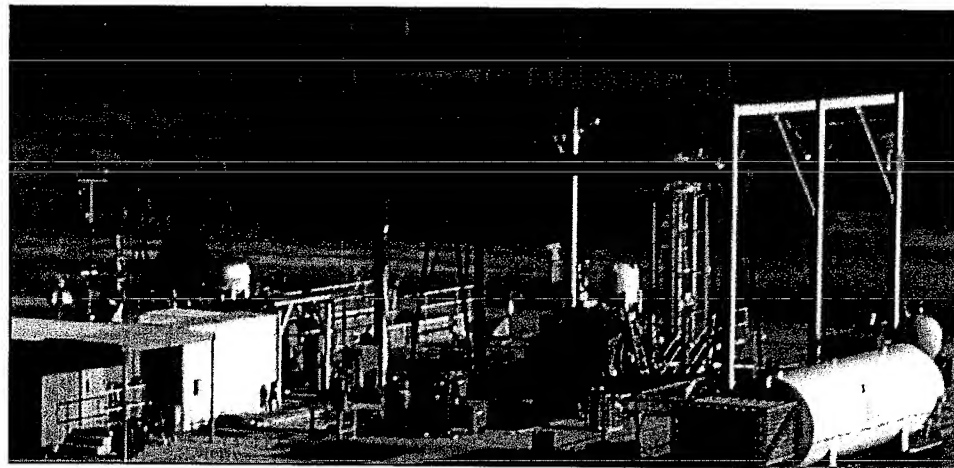


**E-1**

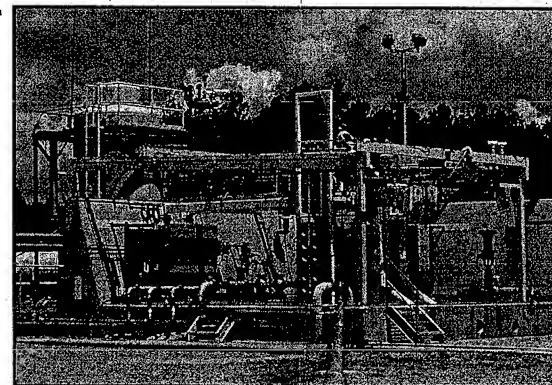
**Bartt J. Hebert**  
**Propulsion Test Directorate**  
**NASA, Stennis Space Center**



**E-2**



**E-3**





# E-Complex

Stennis Space Center

- E Complex Comprised of Three Test Stands
  - E-1 Having Three (3) Test Cells
  - E-2 Having Two (2) Test Cells
  - E-3 Having Two (2) Test Cells
- Versatile Test Complex
  - Thrust Chambers (sub-scale to full scale)
  - Turbopump Assemblies
  - Preburners
  - Engine Systems
- Multiple Propellants
- High Flow Rate Capabilities
- High Delivery Pressure Capabilities





# E-Complex History

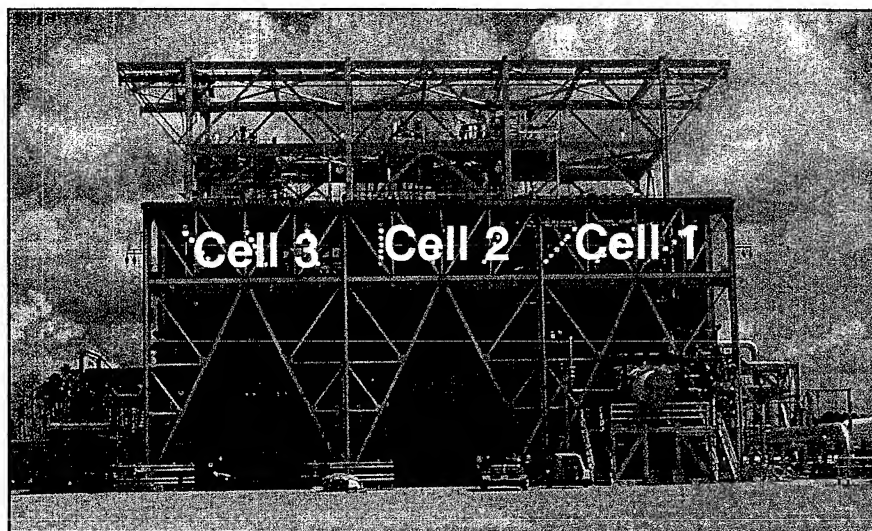
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- Late 1980s/Early 1990s
  - DoD/NASA Advanced Launch System and National Launch System
  - National Aerospace Plane
- Construction Starts
  - E-1 1989
  - E-2 1991
  - E-3 1995
- First Test
  - E-1 1999
  - E-2 1994
  - E-3 1995



# E-1 Test Stand Capabilities

Stennis Space Center



- General Pressure Capabilities

- $\text{LO}_2/\text{LH}_2 \sim 8,500$  psia
- Support Fluids  $\sim 15,000$  psia
- Support Systems: GHe, GN, GOX, Hydraulics, TEA/TEB

- E-1 Cell 1
  - Pressure-Fed  $\text{LO}_2/\text{LH}_2$  & Hybrid-Based Test Articles
  - Thrust Loads up to  $750\text{K lb}_f$  (horizontal)
- E-1 Cell 2
  - $\text{LH}_2$  Turbopump & Preburner Assembly Testing
  - Thrust Loads up to  $60\text{K lb}_f$
- E-1 Cell 3
  - $\text{LO}_2$  Turbopump & Preburner Assembly Testing
  - Thrust Loads up to  $60\text{K lb}_f$

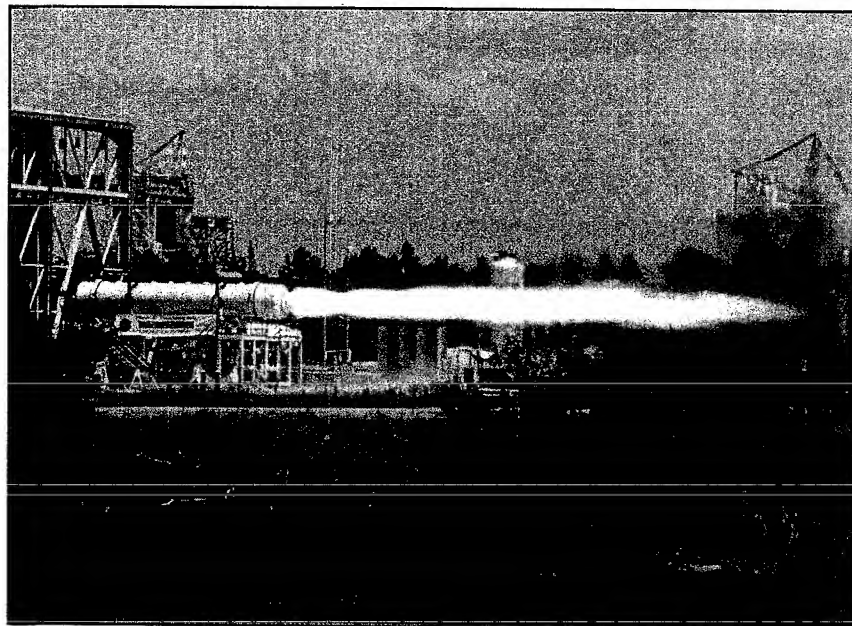




# E-1 Test Stand Activities

Stennis Space Center

## 250K Hybrid Motor Program



- Conducted (4) Hotfire Test at E-1 Cell 1
- LO<sub>2</sub> Propellants
- Thrust ~ 250K lb<sub>f</sub>
- Phase 1 Testing Completed Late 1999 (3 tests)
- Phase 2 Testing Completed Early 2002 (1 test)
- Achieved 35 second Duration Steady State Test at Full Thrust





# E-1 Test Stand Activities

Stennis Space Center

## Ultra Low Cost Engine (ULCE) Program

- Conducted (15) Hotfire Tests at E-1 Cell 1
- Tested TRW, Inc. Pintle-Based ULCE at E1 Cell 1
- $\text{LO}_2/\text{LH}_2$  Propellants
- Thrust  $\sim 650\text{K lb}_f$
- Testing Completed Late-2000
- Achieved 8 second Duration Steady State Test at Full Thrust

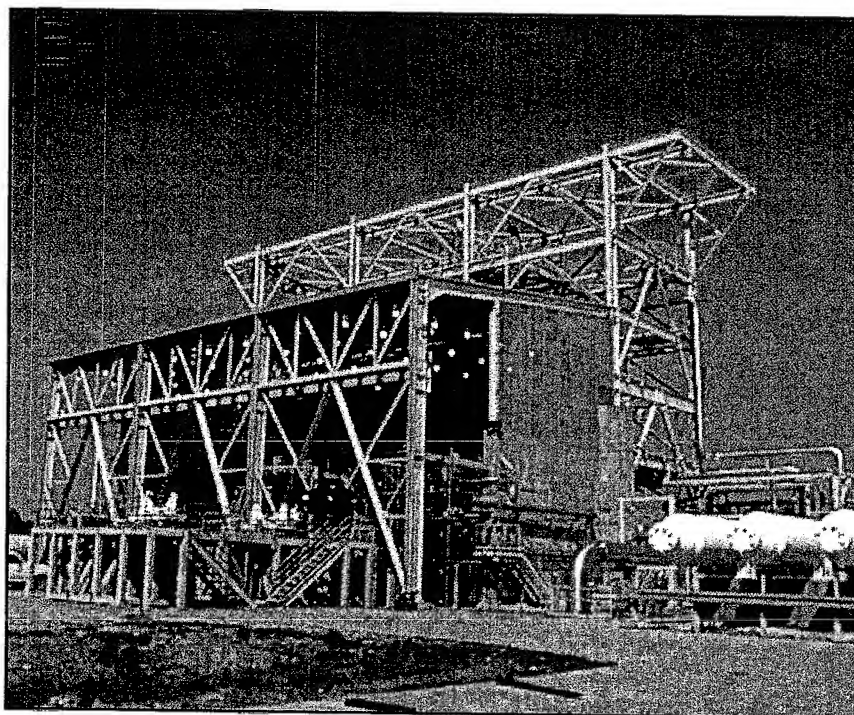
## Integrated Powerhead Demonstration (IPD) Program

- Joint NASA/Air Force Program
- Tested IPD LOX Turbopump at E-1 Cell 3
- HP GN Turbine Drive
- LP LN Feed
- Phase 1 Testing Completed Late-2001
- Achieved Steady State Test at 75% RPL



# E-1 Test Stand Upcoming Programs

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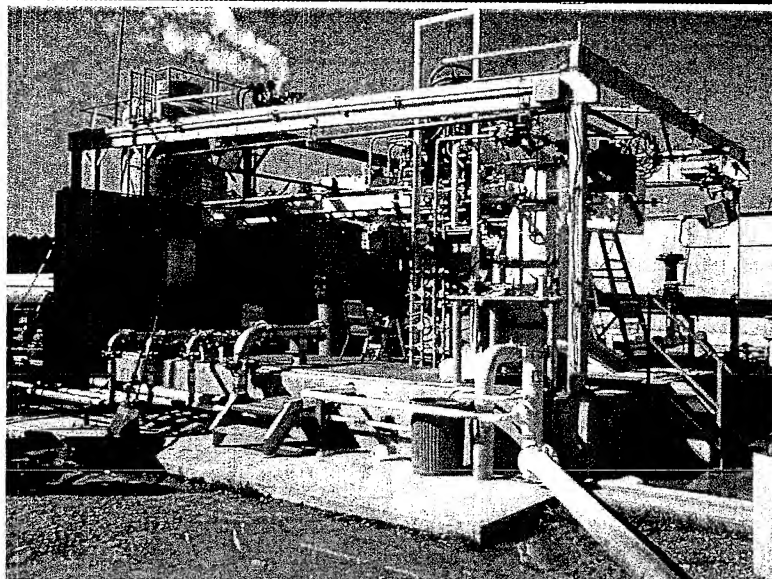


- Cell 1
  - Boeing RS-83 LOX/LH Preburner
  - Aerojet/P&W COBRA LOX/LH Preburner
- Cell 2
  - IPD LH Turbopump Test
  - IPD LH Turbopump Hotfire
  - IPD LH Fuel Rich Preburner
- Cell 3
  - IPD Ox-rich Preburner Test
  - IPD LOX Turbopump Hotfire
  - IPD Integrated System Test

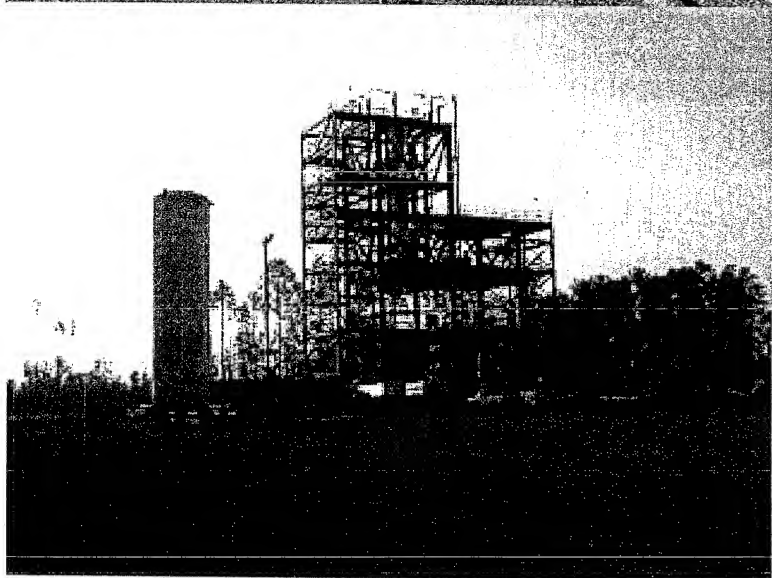


# E-2 Test Stand Capabilities

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- E2 Cell 1
  - Pressure-Fed  $\text{LO}_2$ /RP1 Based Test Articles
  - Thrust Loads up to 100K  $\text{lb}_f$  (horizontal)
  - $\text{LO}_2$ /RP-1 ~ 8,500 psia
  - GN/GH ~ 15,000 psia
  - Hot GH (1,300 F @ 6,000 psi)



- E2 Cell 2
  - $\text{LO}_2$  /RP-1 Engine/Stage Test Articles
  - Loads up to 150K  $\text{lb}_f$
- Support Systems
  - GHe, GN, Hydraulics



# E-2 Test Stand Activities

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Stennis Space Center

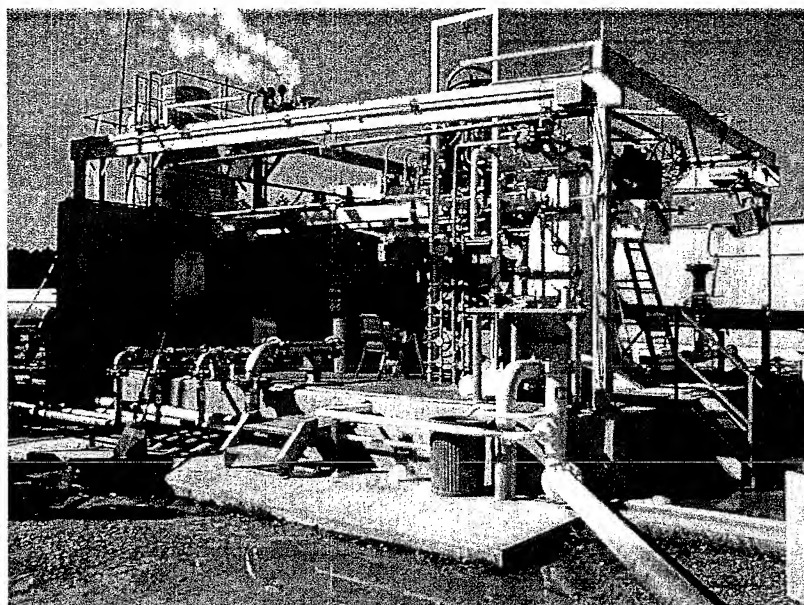
## RS-76 LOX Rich Preburner Program

- Conducted Several Hotfire Test at E-2 Cell 1
- 7,000 psi LO<sub>2</sub>/RP-1 pressure fed
- Thrust ~ 30K lb<sub>f</sub>
- Testing Completed Early 1999
- Achieved 12 second Duration Steady State Test at Full Thrust



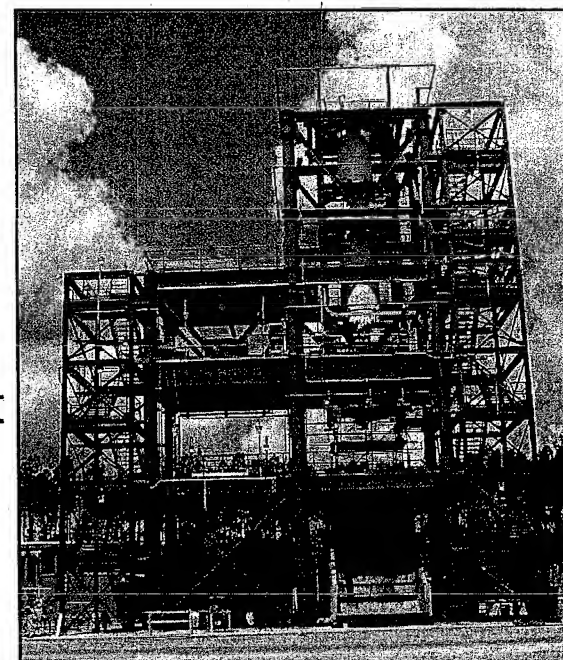
# E-2 Test Stand Upcoming Programs

*Stennis Space Center*



- Cell 1
  - Air Force LR-89 LOX/RP Pressure Fed 75 k-lb Thrust Chamber
  - Boeing RS-84 LOX/RP Sub-Scale Preburner and TCA

- Cell 2
  - Air Force/Orbital Upper Stage Flight Experiment ( $\text{H}_2\text{O}_2$ /JP-8)



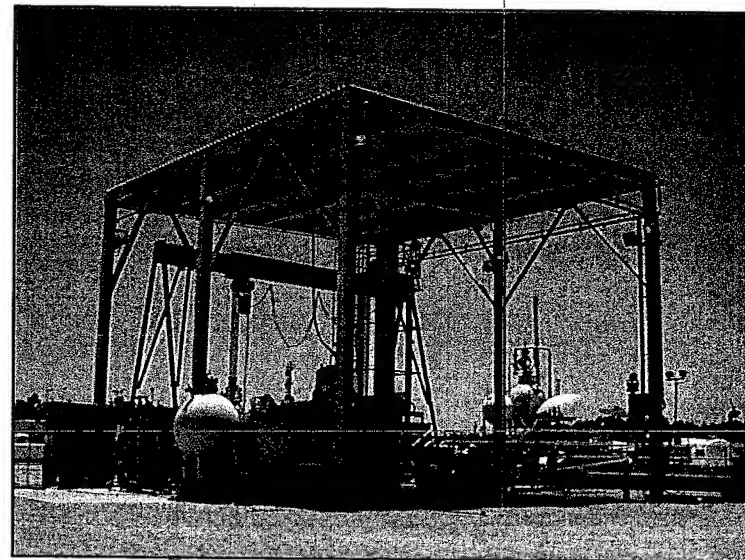


# E-3 Test Stand Capabilities

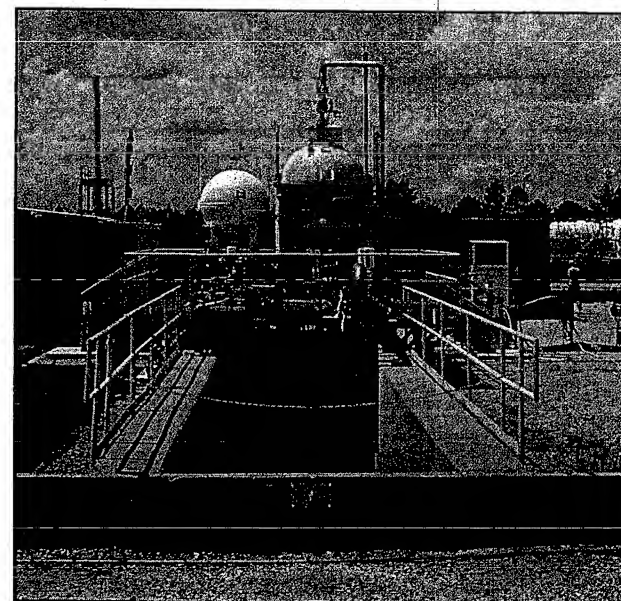
Stennis Space Center

- E3 Test Stand Capabilities
  - Rocket Engine Component & Sub-Scale Engine Development
  - Comprised of Two (2) Test Cells
- E3 Cell 1
  - Horizontal Testing
  - Propellants:  $\text{LO}_2$ ,  $\text{GOX}$ , Hydrocarbons,  $\text{GH}_2$
  - Support Systems:  $\text{LN}_2$ ,  $\text{GN}_2$ ,  $\text{GHe}$
  - Thrust Loads up to 60K  $\text{lb}_f$
- E3 Cell 2
  - Vertical Testing
  - Propellants:  $\text{LO}_2$ ,  $\text{H}_2\text{O}_2$ , Hydrocarbons
  - Support Systems :  $\text{LN}_2$ ,  $\text{GN}_2$ ,  $\text{GHe}$
  - Thrust Loads up to 25K  $\text{lb}_f$

Cell 1



Cell 2





# E-3 Cell 1 Test Stand Activities

Stennis Space Center

## Hybrid Sounding Rocket (HYSR)

- Tested Lockheed Martin Michoud Space Systems HYSR at E-3 Cell 1
- HYSR Designed For Sub-Orbital & Atmospheric Science Missions
- LOX Fed Hybrid-Based Test Article
- Thrust ~ 60K lb<sub>f</sub>
- Achieved Steady State Test at Full Thrust

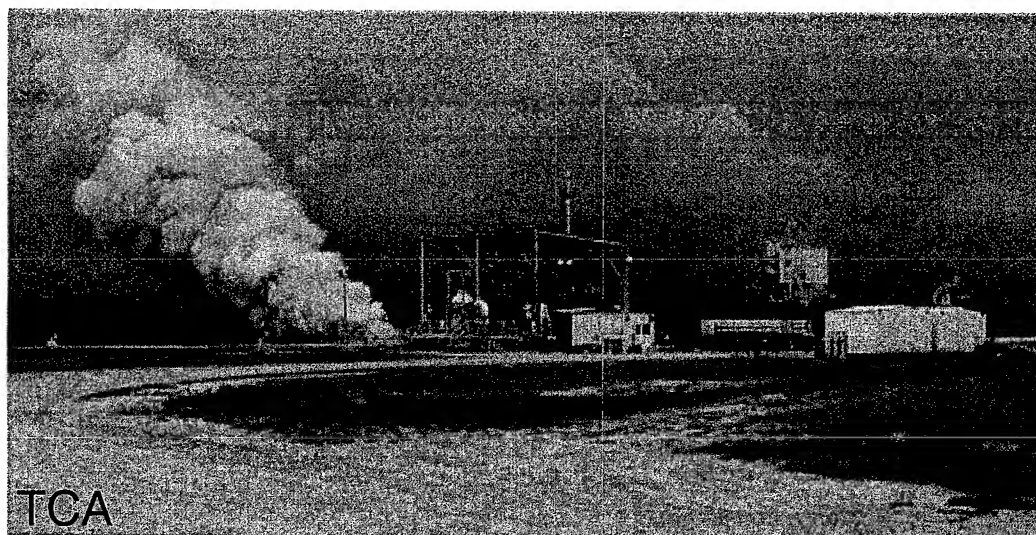




# E-3 Cell 2 Test Stand Activities

Stennis Space Center

## Hydrogen Peroxide Programs (85% to 98%)



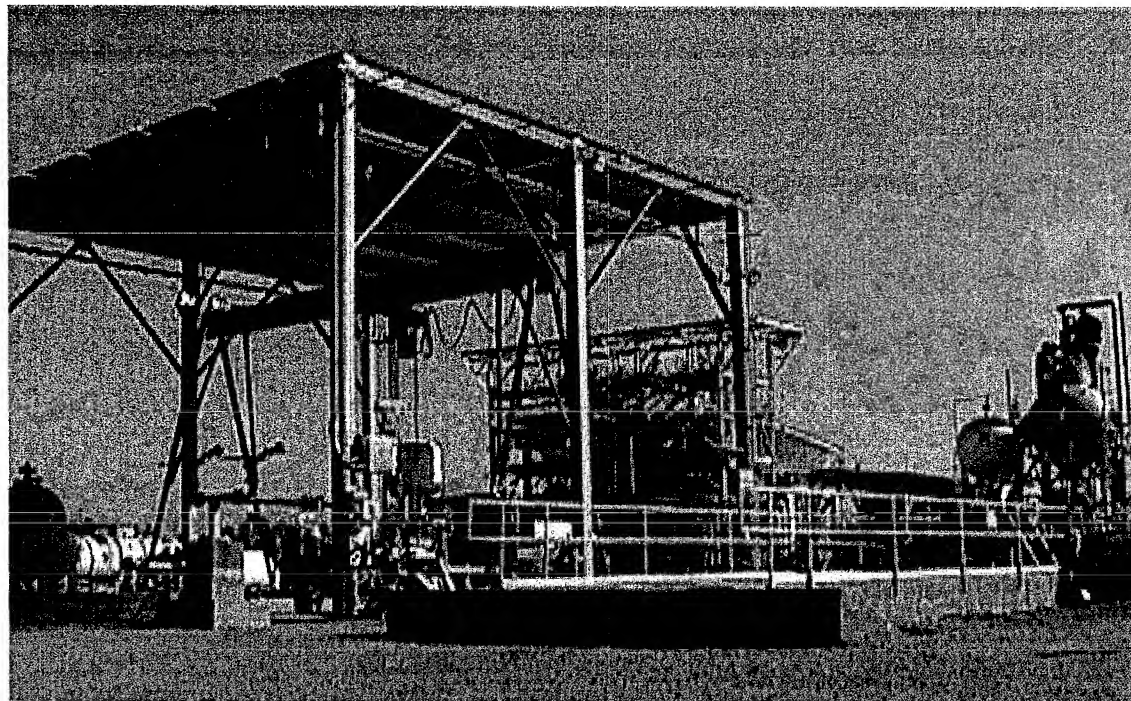
- Tested Several  $\text{H}_2\text{O}_2$  Test Articles
  - Boeing AR2-3
  - Orbital Sciences Corporation TCA
  - Pratt & Whitney and Boeing Catalyst Bed Testing Programs



# E3 Test Stand Upcoming Programs

*Stennis Space Center*

- Cell 1
  - $\text{H}_2\text{O}_2$ /JP Turbopump Development

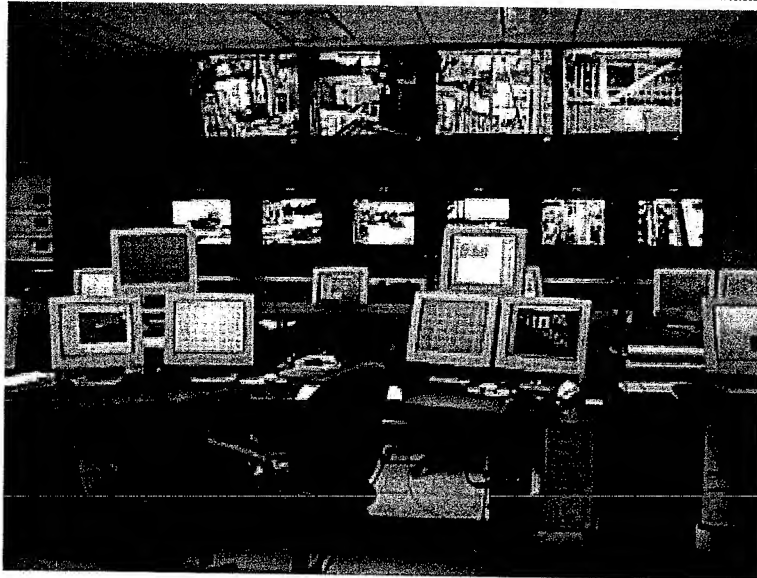


- Cell 2
  - $\text{H}_2\text{O}_2$ /JP Thrust Chamber Development



# E-Complex Control Rooms

*Stennis Space Center*



E-1 Control Room



E-2 Control Room



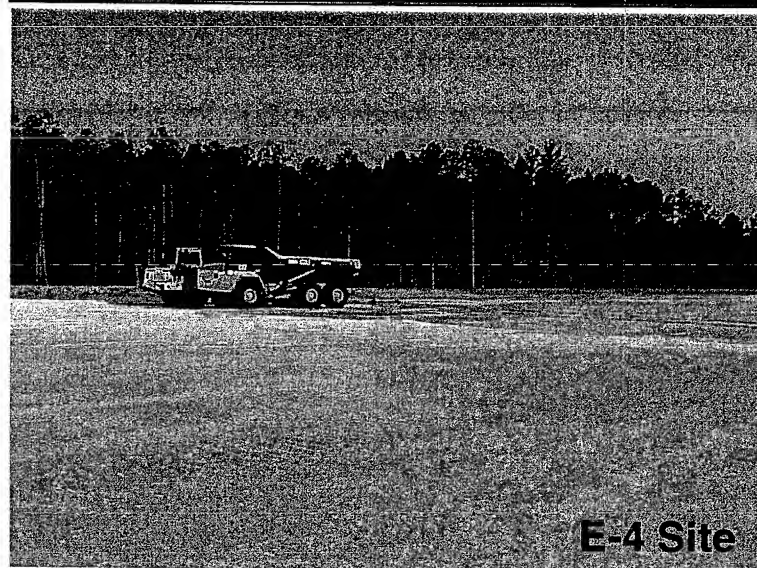
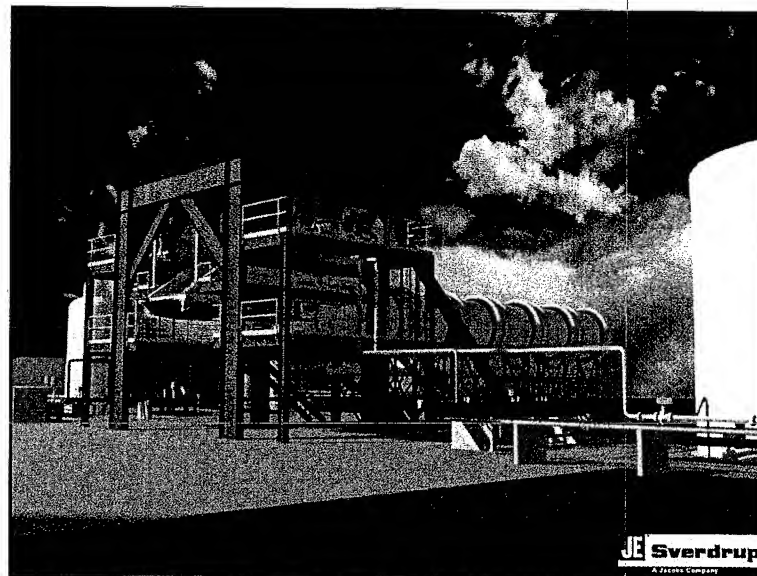
E-3 Control Room



# E-4 Future Test Stand

*Stennis Space Center*

- Designed for Testing of RBCC Engine Systems and Powerpack Assemblies
  - 50 K Thrust Capability
  - Low Pressure JP-7 and H<sub>2</sub>O<sub>2</sub> Propellant Supply
- Single-Cell Test Stand
- Facility Construction Complete 6/04/04
- Facility Activation/Checkout Complete 2/07/05

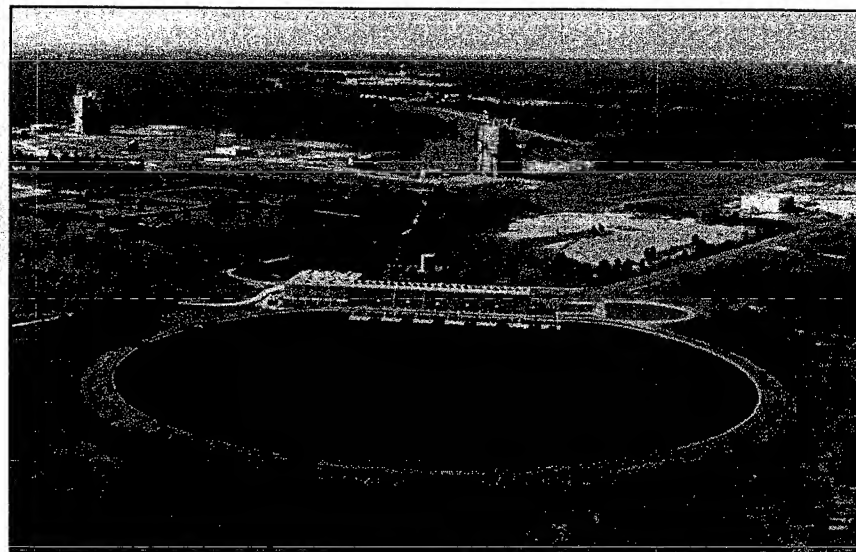
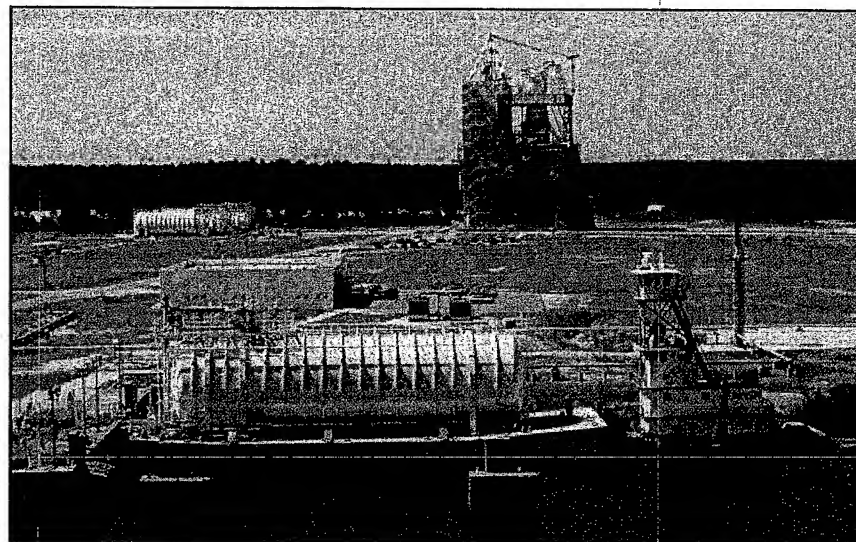




# SSC Propulsion Test Support Services

*Stennis Space Center*

**Stan Gill**  
**Propulsion Test Directorate**  
**NASA, Stennis Space Center**







# SSC Test Support Services

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*Stennis Space Center*

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- SSC has all the required functions along with some unique support facilities to support propulsion testing.
  - High Pressure Gas Facility
  - High Pressure Industrial Water
  - Cryogenic Propellant Storage/Transfer Facility
  - Laboratories
  - Shops
  - Utilities
  - Other Services



# High Pressure Gas Facility (HPGF)

*Stennis Space Center*

- Helium System

- > Max Pressure 4,500 psig
- > 2 Storage Vessels - each 10,000 ft<sup>3</sup>
- > Max hydrocarbon content - 10 ppm

- Hydrogen System

- > Max Pressure 3,000 psig
- > 1 Storage Vessel – 20,000 gal

- High Pressure Air System

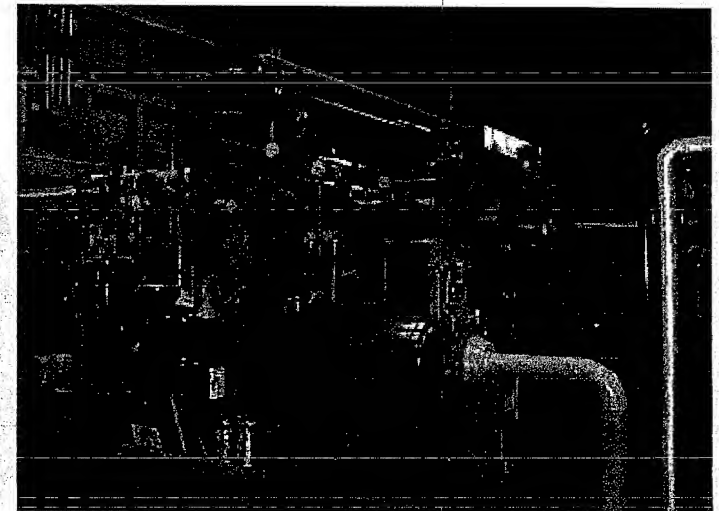
- > Max Pressure 2,800 psig
- > Missile grade air

- Nitrogen System

- > Max Pressure 4,400 psig
- > 2 Storage Vessels – 63,250 gal and 27,000 gal

- Auxiliary Tube Bank Storage

- > 7 Helium Trailers
- > 7 Nitrogen Trailers
- > 2 Hydrogen Trailers



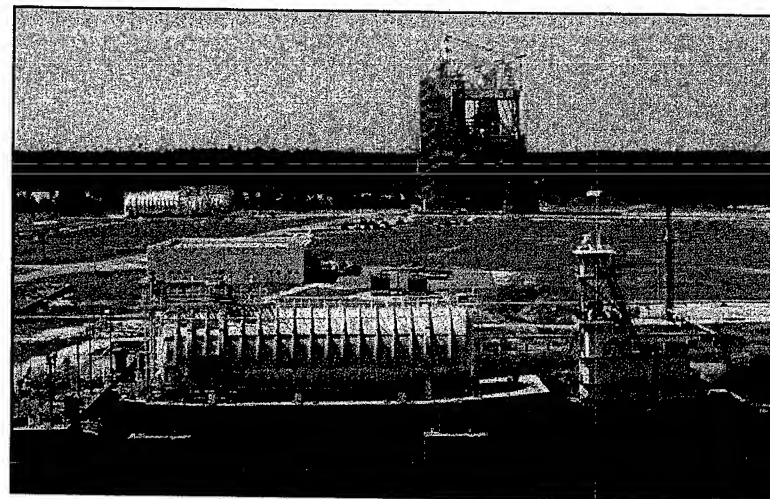
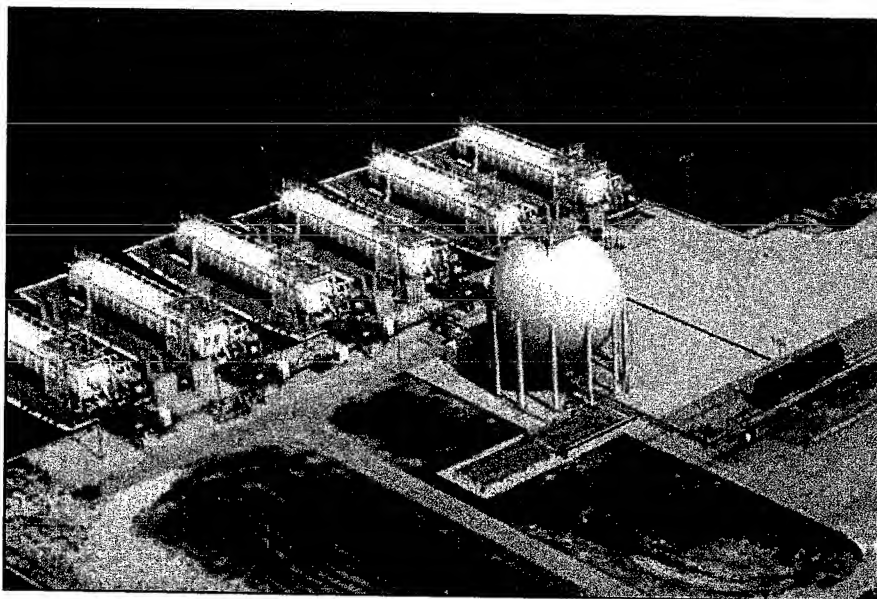




# Cryogenic Propellant Storage Facility

*Stennis Space Center*

- Six LOX Barges – 97,500 gallons each
- Three LH<sub>2</sub> Barges – 250,000 gallons each
- Propellant storage/transfer facility (trailers and barge)
- Integrated canal system for barge traffic
- Control panels for barge systems checkout
- Real-time transfer capability on vertical test stands

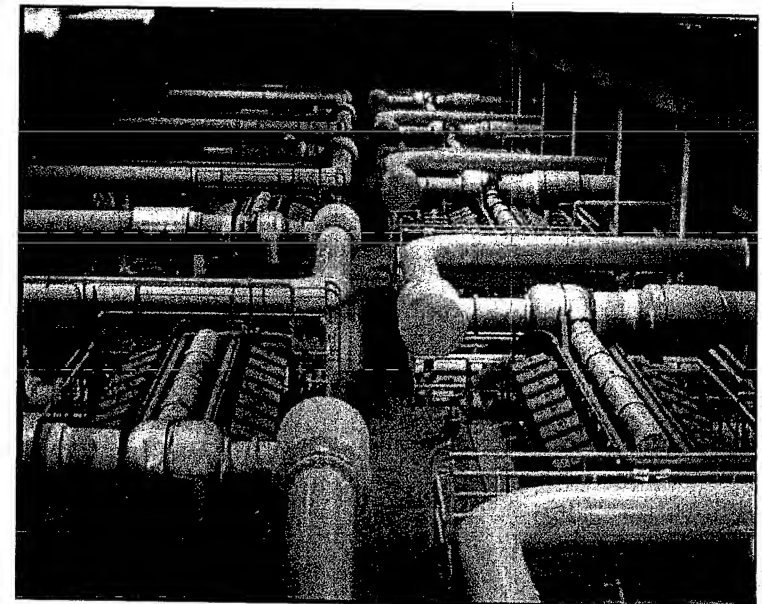
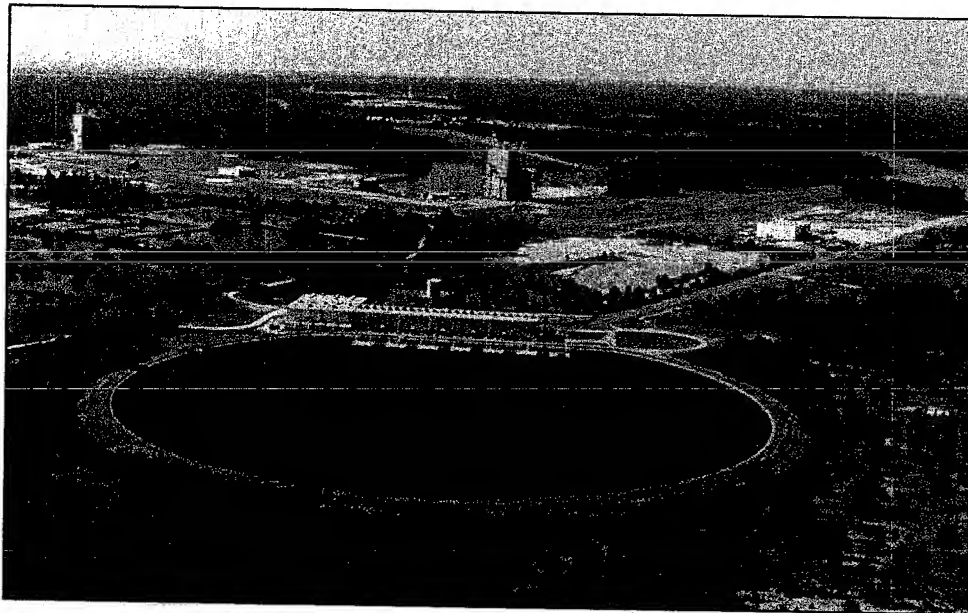




# High Pressure Industrial Water (HPIW)

*Stennis Space Center*

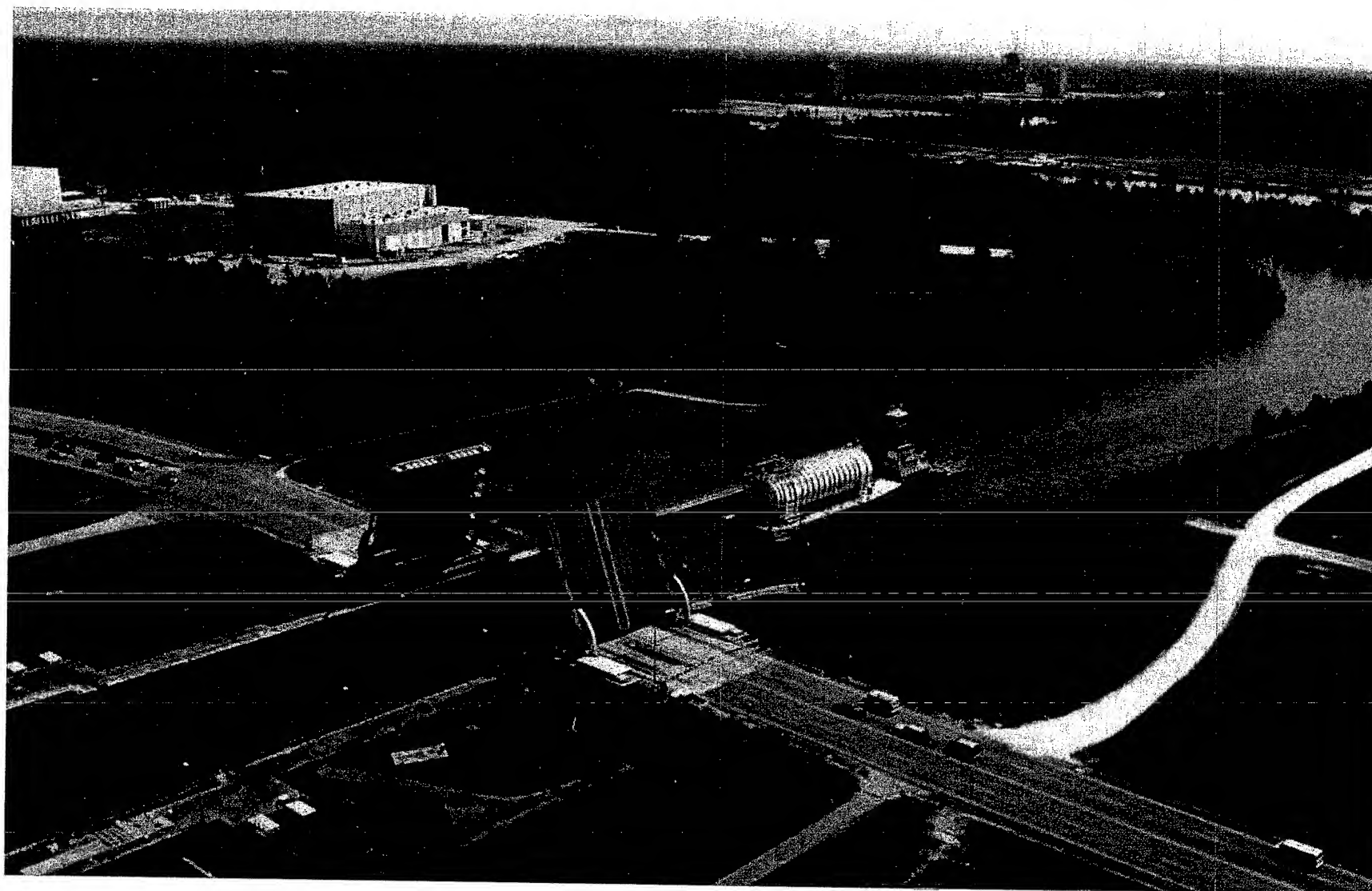
- 66,000,000-gal reservoir with industrial wells
- Ten diesel-driven pumps with a total capacity of 330,000 gal/min for a duration of 40 min.
- Piping and foundation to expand to 13 pumps
- Deluge and cooling water is provided to A-1, A-2, and B-1/B-2





# Bascule Bridge & Lock

*Stennis Space Center*



4/16/02



# Laboratories

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*Stennis Space Center*

- Environmental
- Gas and Material Analysis
- Measurement Standards and Calibration



# **Shops**

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*Stennis Space Center*

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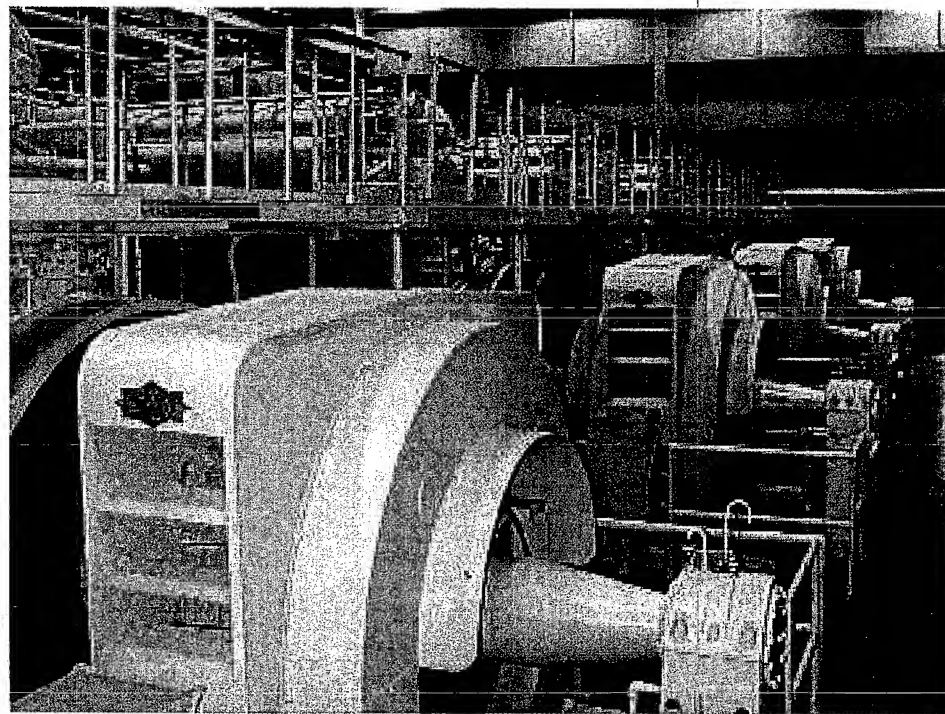
- Carpentry Shop
- Mechanical/Plumbing Shop
- Electric Shop
- Heating, Ventilation, and Air-Conditioning Shop
- Paint Shop
- Weld/Fabrication Shop
- Machine Shop
- Component Support
- Nondestructive Test and Evaluation Laboratory



# Utilities

*Stennis Space Center*

- Electric
  - (2) 13.8 kilovolt feeds to SSC
  - Emergency generators
  - (4) 1,875 KVA, diesel-driven generators
  - Located in the HPIW Facility
  - Supports A/B Complex activities



Four Diesel-Driven Generators at HPIW



# Other Services

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*Stennis Space Center*

- Medical Clinic/Emergency Response Team
- Wellness/Fitness Facility
- Food Services
- Recreational Association
- Fire Department
- Security Services
- IT Support

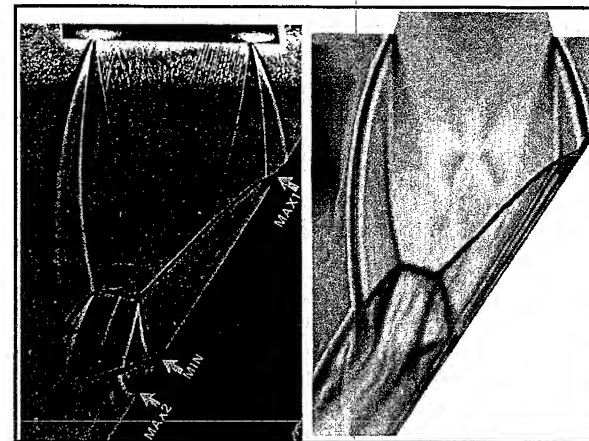




# Engineering and Test Technology

Stennis Space Center

**S. A. Rahman**  
**Engineering Division**  
Propulsion Test Directorate  
NASA, Stennis Space Center



*Technology*



*Design*

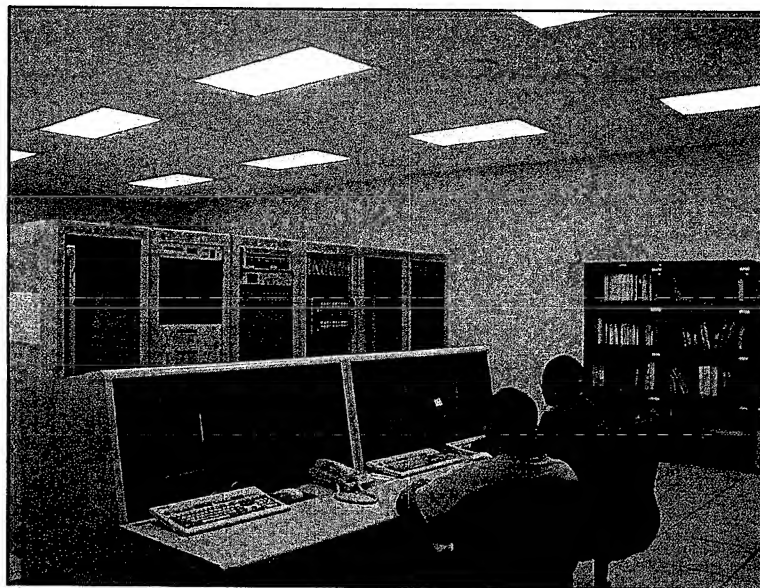


# Engineering: Primary Responsibilities

*Stennis Space Center*

- Test Systems Mechanical Design
- Test Systems Electrical Design
- Technology for Safety & Operability

**Turning Test Requirements  
into Test Systems**



*DACS System Development*



# Engineering of Test Systems

Stennis Space Center

- **Mechanical Test Systems**

- Propellant Supply for Oxidizer, Fuel
- Ignition, Purges, Thrust Mounts
- Supporting Analyses (static/dynamic flow pressure, structural, thermal)

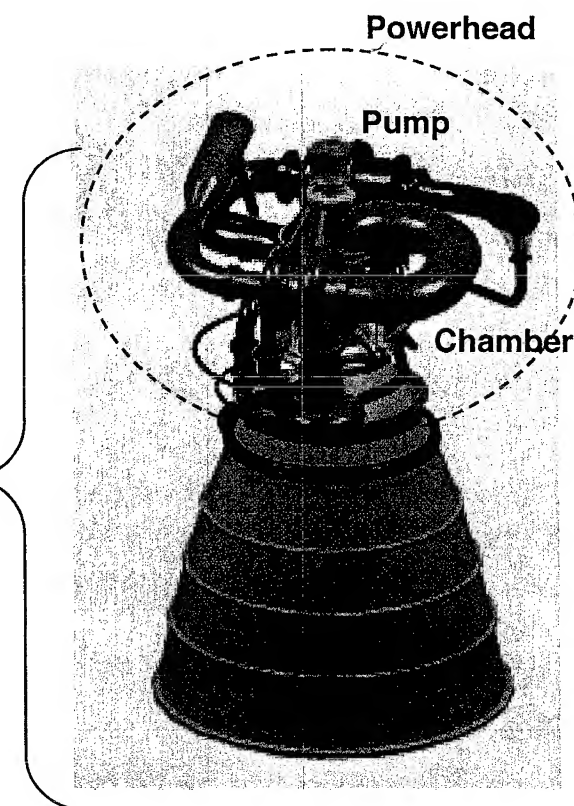
Design – a Systematic way of Mitigating Technical Risk

- **Electrical Test Systems**

- Instrumentation
- Controls
- Low-speed and High-speed Data Acquisition
- Data Processing algorithms
- Ancillary: Video, Power, Gas & Fire Detection

## Test Articles

Pump, Preburner, Thrust Chamber, Powerhead, Engine, Stage





Stennis Space Center

The diagram shows a cross-section of a cylindrical LOX tank. The tank is filled with LOX (liquid oxygen) at the bottom, with a layer of O<sub>2</sub> Vapor above it. A diffuser (AKA stirring device) is positioned in the center of the tank. The height of the diffuser is labeled as 10.0 inches. The tank has a diameter of 104.7 inches and a volume of 547.7 cu ft. The LOX level is indicated by a horizontal line. The tank is connected to a system of pipes and valves. A 6-inch valve is located at the top left, and a P<sub>1</sub> valve is at the top right. An outflow valve is at the bottom right, leading to a test article. A pressure gauge is connected to the top of the tank. A label 'HP-N2 10,000 psi' is in the top left corner.

Stress Von Mises (Maximum)

Max: +3.20338e+06

Min: -5.61540e+00

Original Model

Load: thermal5

2.092e+04  
5.563e+04  
7.042e+04  
1.392e+05  
1.607e+05  
1.202e+06  
9.514e+06  
6.411e+08  
9.208e+09

Thermal stress

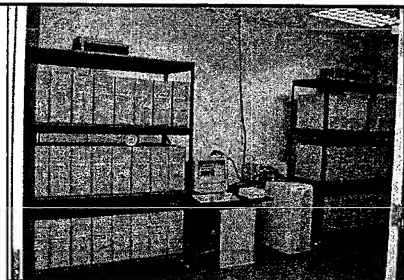
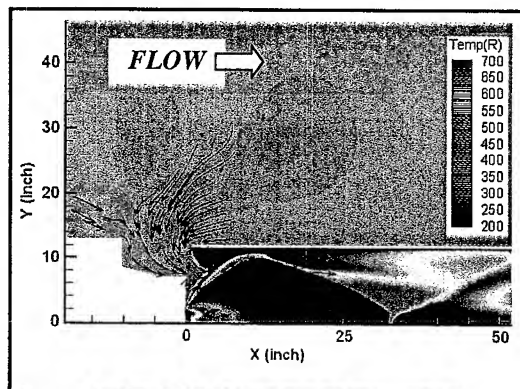




# Test Technology

Stennis Space Center

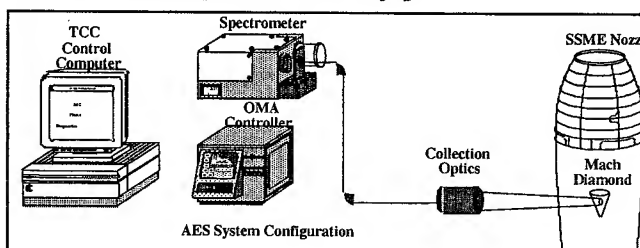
## Computational Fluid Dynamics



PC-Cluster "Super Computer"

Applying State-of-the-Art Technology  
To Support Test Projects & Enhance Safety

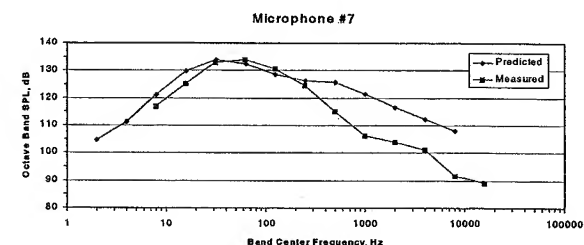
## Plume Spectroscopy



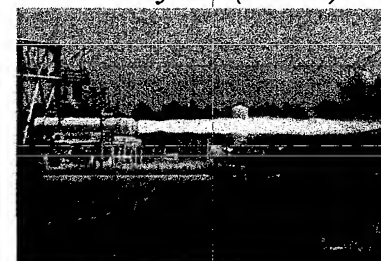
### Plume Diagnostics Instrumentation

Custom spectral analysis systems can detect minute levels of metallic contaminants indicative of abnormal engine wear

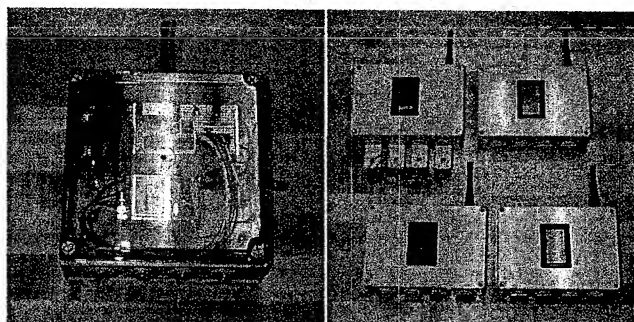
## Acoustic Data & Modeling



### 250K Hybrid (9-9-99)



## Wireless Sensors



Wireless Thermocouples

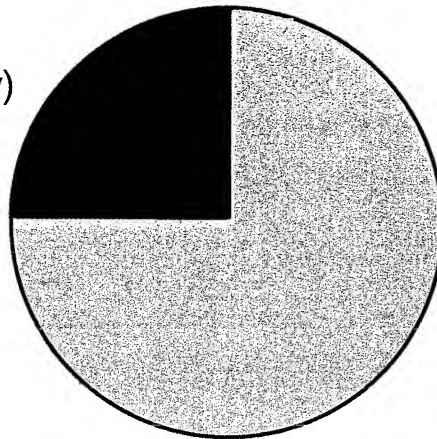
Affiliations with Government  
Technologists, University  
Experts, & NASA Technology  
Transfer programs



# Engineering Workforce & Skills Mix

*Stennis Space Center*

20 NASA Engineers  
(Design/Analysis/Technology)

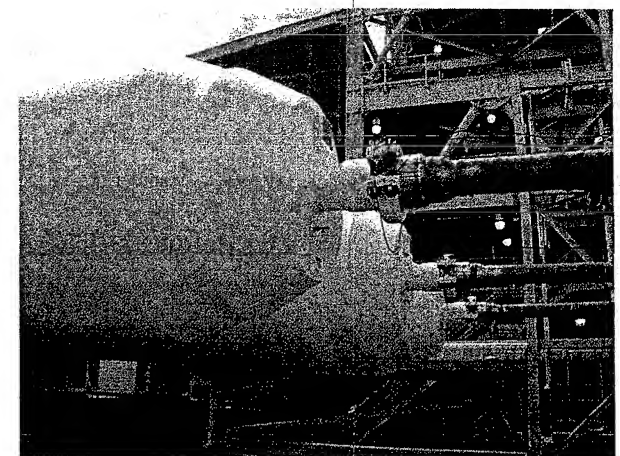


**A Diverse Skills Base within a  
Highly Experienced Workforce**

60 Contractor Engineers  
(Design/Analysis/Technology)

## Skill Areas

- Mechanical Components & Systems Design
- Fluid and Thermodynamic Analyses
- Cryogenic Engineering
- Pressure Vessel Design & Maintenance
- Instrumentation Systems & Special Sensors
- High-Speed/Low-Speed Data Acquisition Systems
- Materials Compatibility ( $O_2$ ,  $H_2$ ,  $RP$  &  $H_2O_2$ )
- Plume Effects Predictions, Measurements, & Diagnostics







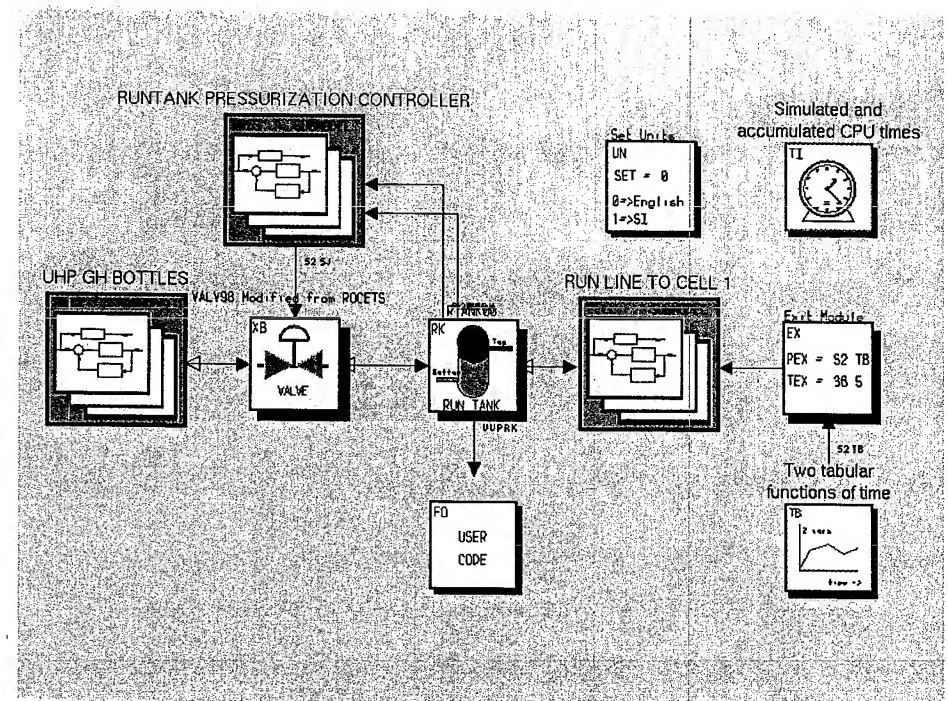
# Engineering Tools

Stennis Space Center

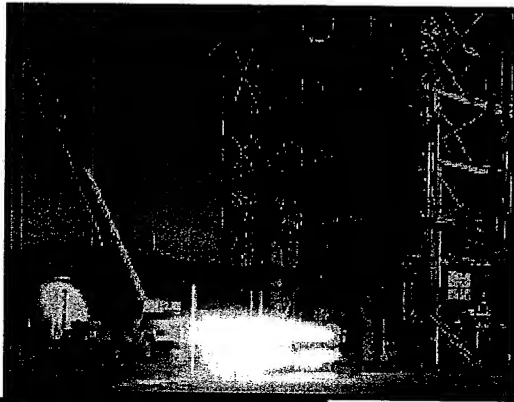
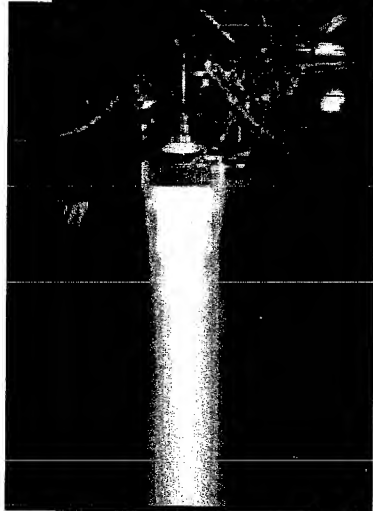
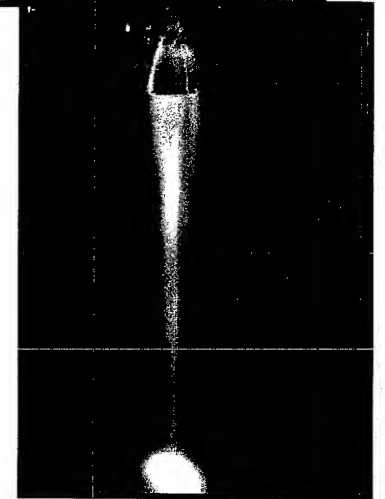
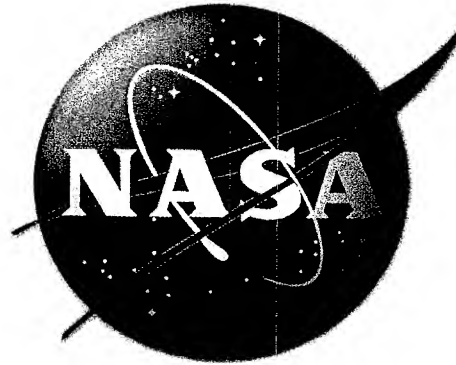
## Industry Standard & Custom Methods

- Pro/Engineer (CAD) & Pro/Mechanica (Analysis)
- ROCETS Code (Rocket Engine Transients Simulation)
- Fanno Flow Code
- NIST properties for real Fluids
- ALGOR Pipeplus
- FDNS (Finite Difference Navier Stokes)
- PLIMP (Plume Impingement)

The Right Tools to Model, Predict & Enhance Test Capabilities

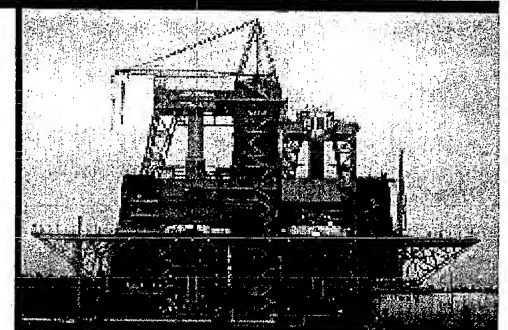
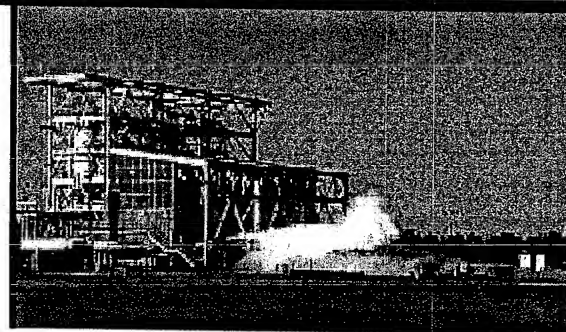


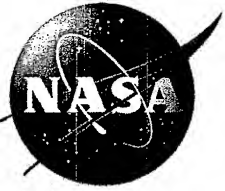




# *Stennis Space Center Propulsion Test Program Office*

April 16, 2002





# *Propulsion Test Program Office Responsibilities*

*Stennis Space Center*



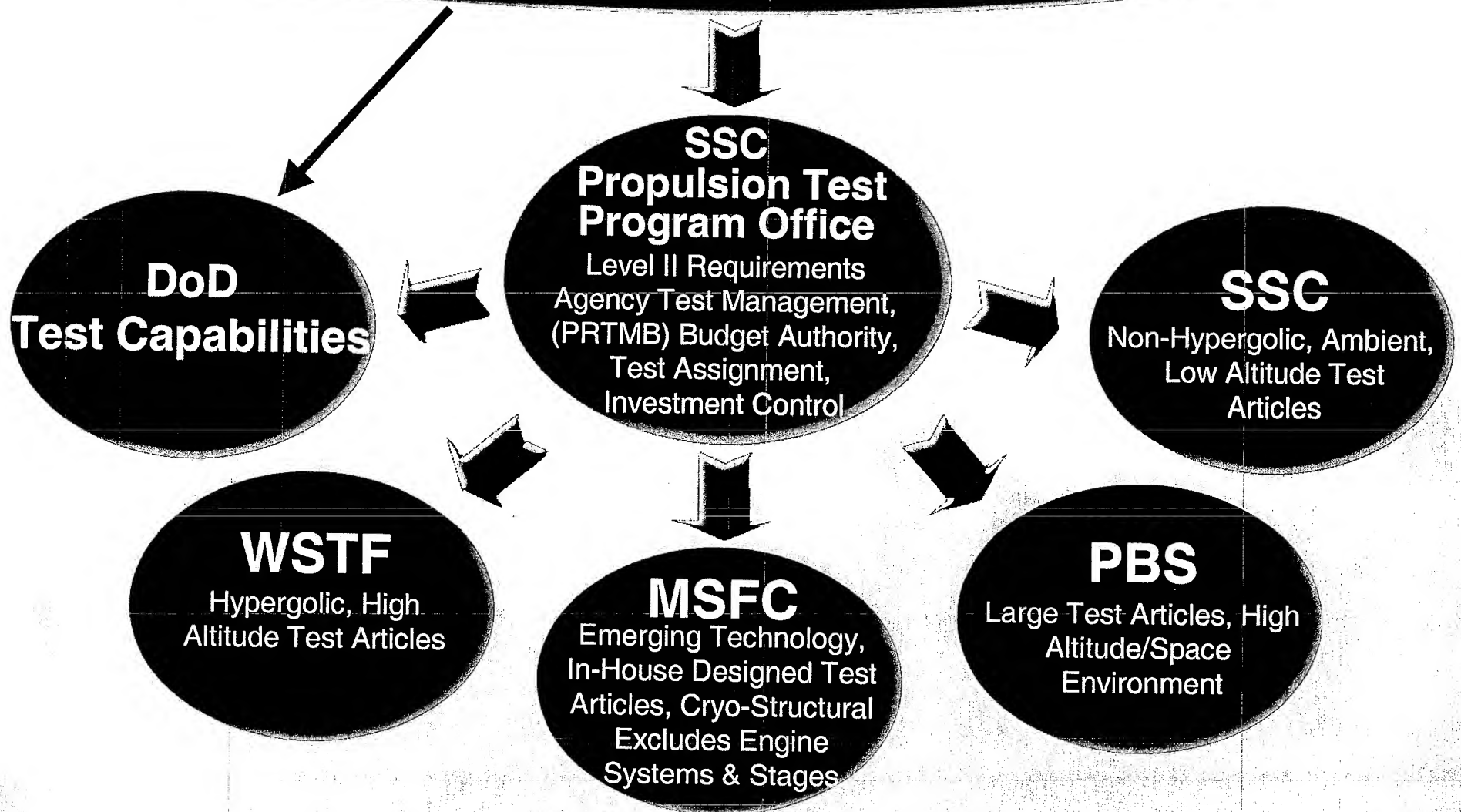
- Manage NASA's rocket propulsion test assets, activities, resources
- Develop testing and facility investments and consolidation strategies
- Set world-class standards for effectiveness and efficiency
- Determine where tests are performed
- Provide full customer services to other Gov. agencies and industry
- Develop and implement advances in test technology
- Improve cooperation with DoD rocket testing



# *Propulsion Test Concept*

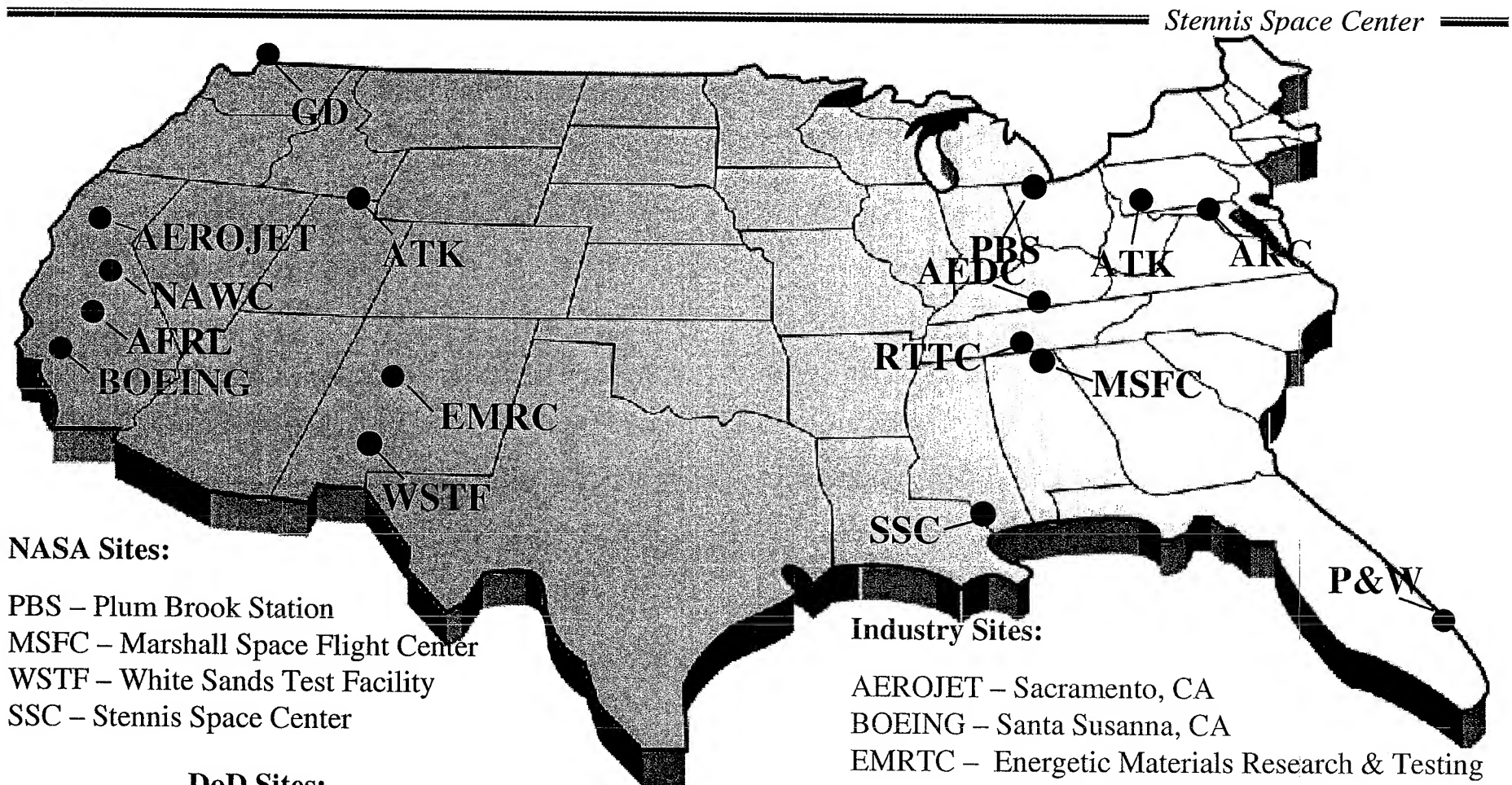


Propulsion Community Customer Requirements and Resources





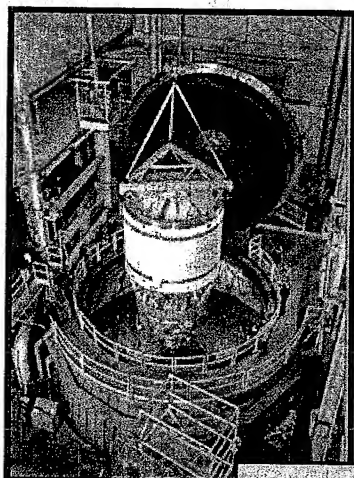
## Nation's Rocket Test Locations



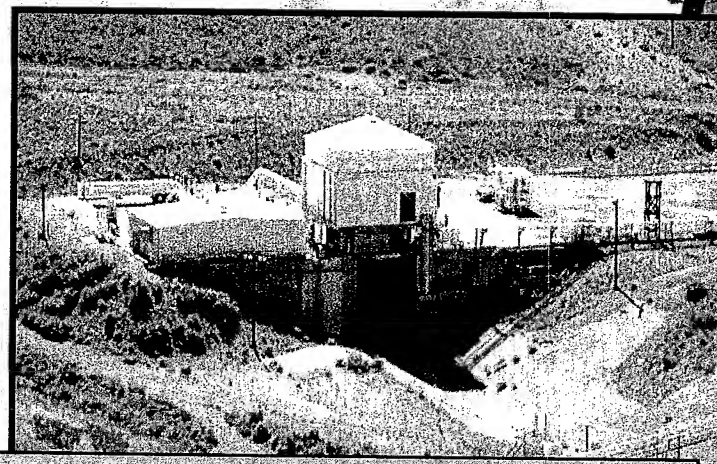




# Summary of NASA's Rocket Test Infrastructure

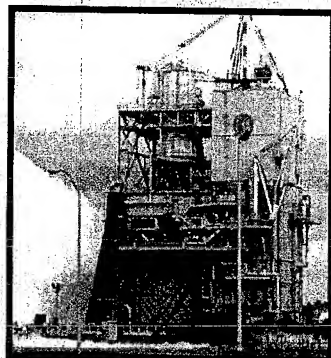


PBS



WSTF

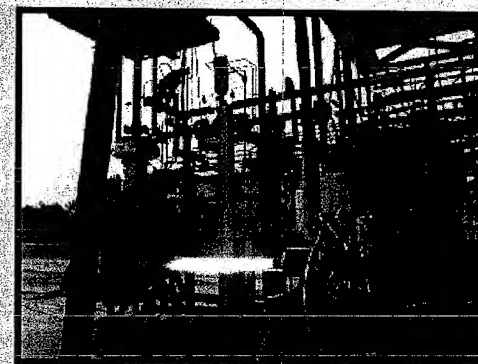
|         | Current Facility Inventory |        |          |            | Removed From Inventory (to date) |           |            |            |
|---------|----------------------------|--------|----------|------------|----------------------------------|-----------|------------|------------|
|         | TOTAL                      | Active | Inactive | Mothballed | TOTAL                            | Abandoned | Demolished | Non Rocket |
|         | 32                         | 26     | 3        | 3          | 11                               | 5         | 2          | 4          |
| SSC     | 12                         | 11     | 0        | 1          | 1                                | 0         | 0          | 1          |
| GRC/PBS | 1                          | 1      | 0        | 0          | 2                                | 2         | 0          | 0          |
| MSFC    | 10                         | 7      | 1        | 2          | 7                                | 3         | 2          | 2          |
| WSTF    | 9                          | 5      | 0        | 4          | 1                                | 0         | 0          | 1          |



Current Replacement Value = ~ \$2B

SSC

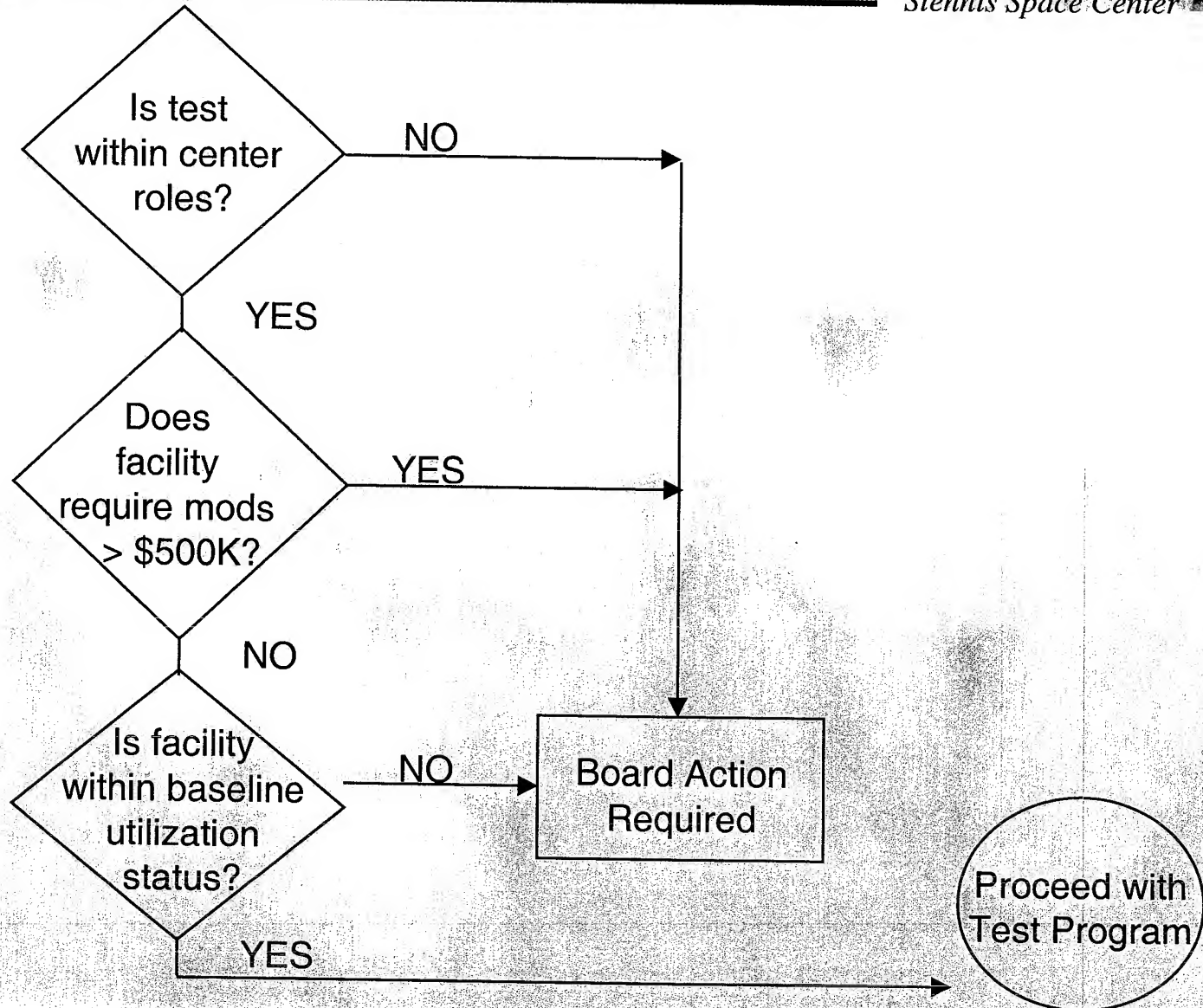
MSFC





# RPTMB Process Flow

Stennis Space Center





# NASA Facilities Utilization Schedule (sample)



| Task Name                                                | Start    | Finish   | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|----------------------------------------------------------|----------|----------|------|------|------|------|------|------|------|------|
| <b>Stennis Space Center Utilization Schedule</b>         |          |          |      |      |      |      |      |      |      |      |
| A-1 TEST STAND                                           | 11/07/96 | 07/01/20 |      |      |      |      |      |      |      |      |
| A-2 TEST STAND                                           | 04/16/01 | 04/03/12 |      |      |      |      |      |      |      |      |
| B-1 TEST STAND                                           | 11/07/96 | 07/01/20 |      |      |      |      |      |      |      |      |
| B-2 TEST STAND                                           | 06/02/99 | 12/29/06 |      |      |      |      |      |      |      |      |
| E-1 TEST FACILITY                                        | 12/07/00 | 11/15/10 |      |      |      |      |      |      |      |      |
| CELL 1                                                   | 12/25/00 | 12/31/10 |      |      |      |      |      |      |      |      |
| CELL 2                                                   | 01/02/01 | 12/31/10 |      |      |      |      |      |      |      |      |
| CELL 3                                                   | 01/02/01 | 12/31/10 |      |      |      |      |      |      |      |      |
| E-2 TEST FACILITY                                        | 12/25/00 | 12/31/10 |      |      |      |      |      |      |      |      |
| CELL 1                                                   | 01/03/00 | 12/31/10 |      |      |      |      |      |      |      |      |
| CELL 2 (Vertical Stand)                                  | 10/16/00 | 12/31/10 |      |      |      |      |      |      |      |      |
| E-3 TEST FACILITY                                        | 01/03/00 | 02/27/04 |      |      |      |      |      |      |      |      |
| CELL 1                                                   | 10/31/00 | 05/30/03 |      |      |      |      |      |      |      |      |
| CELL 2                                                   | 10/31/00 | 05/30/03 |      |      |      |      |      |      |      |      |
| E-4 TEST FACILITY                                        | 05/15/01 | 12/31/02 |      |      |      |      |      |      |      |      |
|                                                          | 02/02/01 | 12/30/05 |      |      |      |      |      |      |      |      |
| <b>Marshall Space Flight Center Utilization Schedule</b> |          |          |      |      |      |      |      |      |      |      |
| TEST STAND 115                                           | 01/06/95 | 12/06/07 |      |      |      |      |      |      |      |      |
| TEST STAND 116                                           | 10/14/99 | 10/24/06 |      |      |      |      |      |      |      |      |
| TEST STAND 500                                           | 03/05/99 | 12/06/07 |      |      |      |      |      |      |      |      |
| TEST STAND SPTA                                          | 03/17/98 | 07/13/05 |      |      |      |      |      |      |      |      |
| TEST STAND 4670                                          | 11/30/99 | 09/21/07 |      |      |      |      |      |      |      |      |
| STTW Inactive-Abandoned                                  | 10/01/00 | 08/22/05 |      |      |      |      |      |      |      |      |
| SIV B Inactive-Abandoned                                 | 07/11/95 | 07/26/05 |      |      |      |      |      |      |      |      |
| SIV B Inactive-Abandoned                                 | 07/11/95 | 07/26/05 |      |      |      |      |      |      |      |      |
| STTE Inactive-Abandoned                                  | 01/06/95 | 01/20/06 |      |      |      |      |      |      |      |      |
| <b>Glenn Research Center Utilization Schedule</b>        |          |          |      |      |      |      |      |      |      |      |
| GRC B2                                                   | 12/28/98 | 12/29/06 |      |      |      |      |      |      |      |      |
| K SITE                                                   | 07/24/00 | 12/24/04 |      |      |      |      |      |      |      |      |
| RETF B                                                   | 11/02/99 | 12/29/06 |      |      |      |      |      |      |      |      |
| Inactive-Abandoned                                       | 12/28/98 | 09/29/06 |      |      |      |      |      |      |      |      |
| <b>White Sands Test Facility Utilization Schedule</b>    |          |          |      |      |      |      |      |      |      |      |
| TEST STAND 301                                           | 04/22/98 | 06/18/13 |      |      |      |      |      |      |      |      |
| TEST STAND 302                                           | 06/17/98 | 05/31/11 |      |      |      |      |      |      |      |      |
| TEST STAND 303                                           | 01/14/02 | 03/12/10 |      |      |      |      |      |      |      |      |
| TEST STAND 328                                           | 04/22/98 | 06/09/10 |      |      |      |      |      |      |      |      |
| TEST STAND 401                                           | 11/28/00 | 11/08/10 |      |      |      |      |      |      |      |      |
| TEST STAND 402                                           | 04/27/00 | 06/18/13 |      |      |      |      |      |      |      |      |
| TEST STAND 403                                           | 08/03/99 | 01/29/04 |      |      |      |      |      |      |      |      |
| TEST STAND 405                                           | 06/15/98 | 07/16/10 |      |      |      |      |      |      |      |      |
|                                                          | 03/15/00 | 12/15/10 |      |      |      |      |      |      |      |      |

Test Stand Active Project



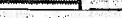
Pending Project



Inactive-Mothballed



Inactive for Rocket Hot Fire



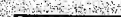
Inactive-Available



Under Construction/Activation



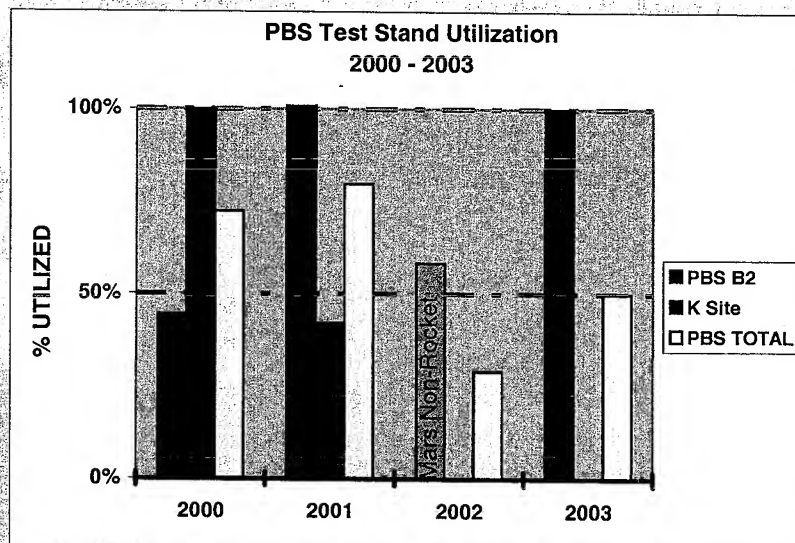
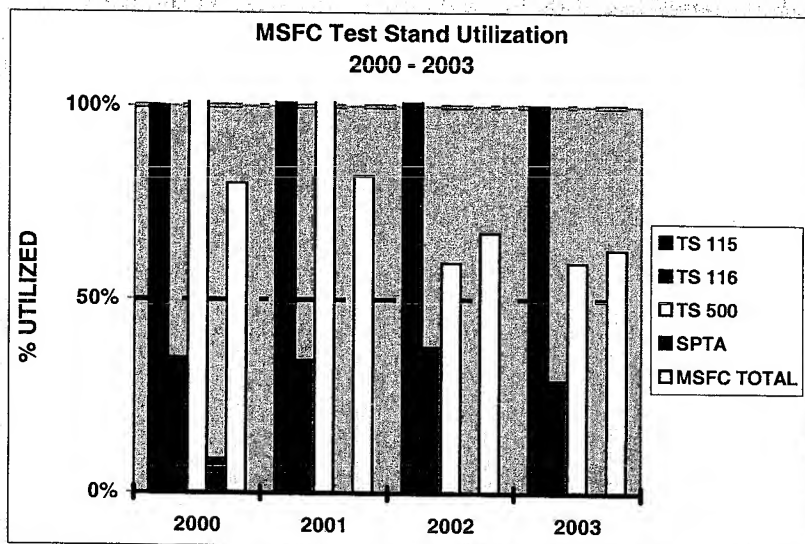
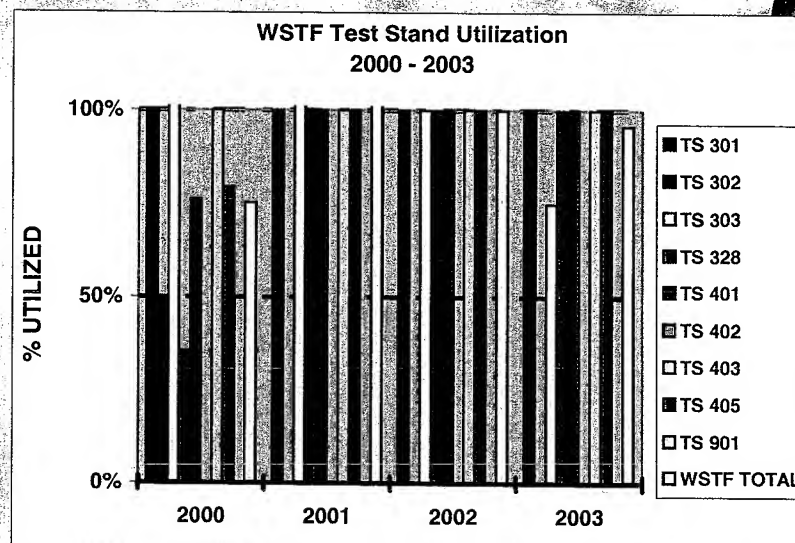
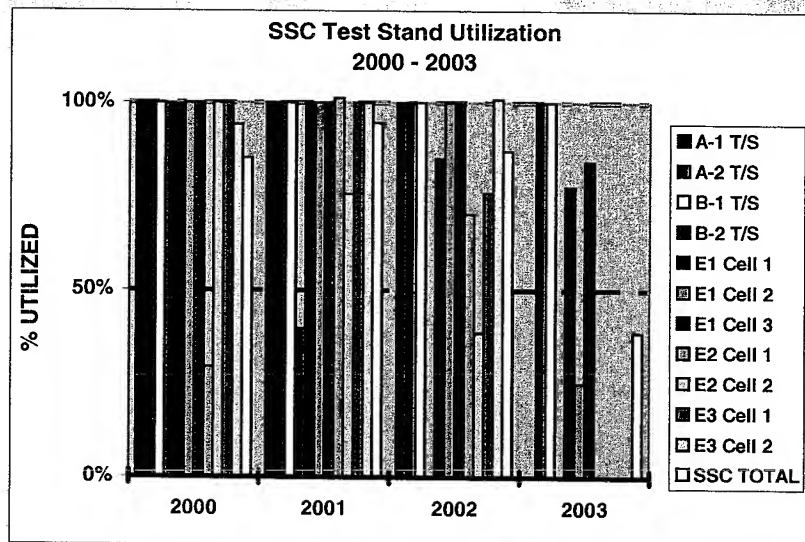
Inactive-Abandoned







# NASA Test Stand Utilization\*



\* NOTE: Active/Inactive/Mothballed Test Stands Included. Based on 360 days in the year. Test Stands are equally weighted toward Site Total. Inactive, Mothballed Test Stands require some level of investment to re-activate.

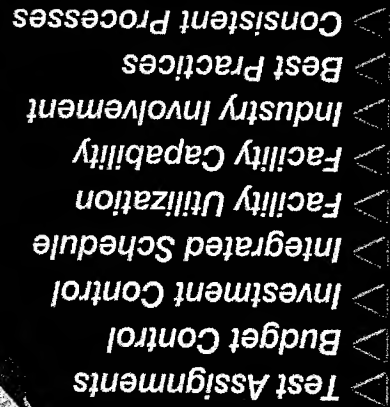


# Test Stand Capabilities Database (sample)



| Site | Test Stand   | Cell Name    | Max Thrust | Altitude | Test Article | Diffuser | Status     | Condition | Propellant | Volume   | Pressure |
|------|--------------|--------------|------------|----------|--------------|----------|------------|-----------|------------|----------|----------|
| AEDC | J-2A         | J-2A         | 20         | 450      | 32 x 18      | 220      | Abandoned  | Poor      |            |          |          |
| AEDC | J-6          | J-6          | 1500       | 100      | 62 x 26      | 240      | Active     | Excellent | Solid      | 1        | 1        |
| AEDC | J-5          | J-5          | 300        | 100      | 50 x 16      | 102      | Mothballed | Excellent | Solid      | 1        | 1        |
| AEDC | J-4          | J-4          | 1500       | 100      | 125 x 48     | 480      | Inactive   | Excellent | A50        | 0.35     | 750      |
|      |              |              |            |          |              |          |            |           | LH2        | 10       | 250      |
|      |              |              |            |          |              |          |            |           | LOX        | 4        | 250      |
|      |              |              |            |          |              |          |            |           | Hydrazines | 0.35     | 750      |
|      |              |              |            |          |              |          |            |           | N2O4       | 0.35     | 750      |
|      |              |              |            |          |              |          |            |           | N2H4       | 0.35     | 750      |
| AFRL | -650130.0417 | -650130.0417 | 1800       | Ambient  | 12 x 18      | N/A      | Active     | Excellent | LOX        | 75       | 150      |
|      |              |              |            |          |              |          |            |           | Hydrazines | 28       | 165      |
|      |              |              |            |          |              |          |            |           | Hydrazines | 58       | 35       |
|      |              |              |            |          |              |          |            |           | RP-1       | 60       | 150      |
| AFRL | 1-120 1B     | 1-120 1B     | 6000       | Ambient  | 12 x 18      | N/A      | Mothballed |           | LOX        | 75       | 150      |
|      |              |              |            |          |              |          |            |           | LOX        | 750      | 15       |
|      |              |              |            |          |              |          |            |           | RP-1       | 65       | 150      |
| MSFC | TF116        | TF116 (750K) | 100        | Ambient  | 3 x 10       | N/A      | Inactive   | Poor      | GH2        | 1.25 ft3 | 15000    |
|      |              |              |            |          |              |          |            |           | GN2        | 1.25 ft3 | 10000    |
|      |              |              |            |          |              |          |            |           | GN2        | 0.70 ft3 | 8000     |
|      |              |              |            |          |              |          |            |           | LCH4/LH2   | 2        | 8500     |
|      |              |              |            |          |              |          |            |           | LOX        | 3        | 6000     |
| MSFC | TF115        | TF115        | 4          | Ambient  | 3 x 3        | N/A      | Active     | Good      | GH2        | 20 ft3   | 3800     |
|      |              |              |            |          |              |          |            |           | LH2        | 2.2      | 1500     |
|      |              |              |            |          |              |          |            |           | LOX        | 0.5      | 3000     |

**\$71M Savings / 92 Test Assignments**





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*Stennis Space Center*

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**Welcome  
to the  
NASA John C. Stennis Space Center  
Propulsion Test  
Customer Day 2002  
(Day 2)**



# Doing Business with SSC

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*Stennis Space Center*

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- How to contact us
- SSC's evaluation process of your request
  - Does it fit
  - Specific Concerns
  - Type of agreement
  - Estimated (ROM) Cost
- Establishing the project / Project Formulation
  - Requirements by customer
  - Cost estimate and milestone schedule
  - Letter of commitment
  - Rough draft of agreements
- Project Management Activities
  - Single point of contact
  - Detailed requirements
  - Detailed schedules
  - Project Control
- Customer Feedback Opportunities





# How to Contact SSC

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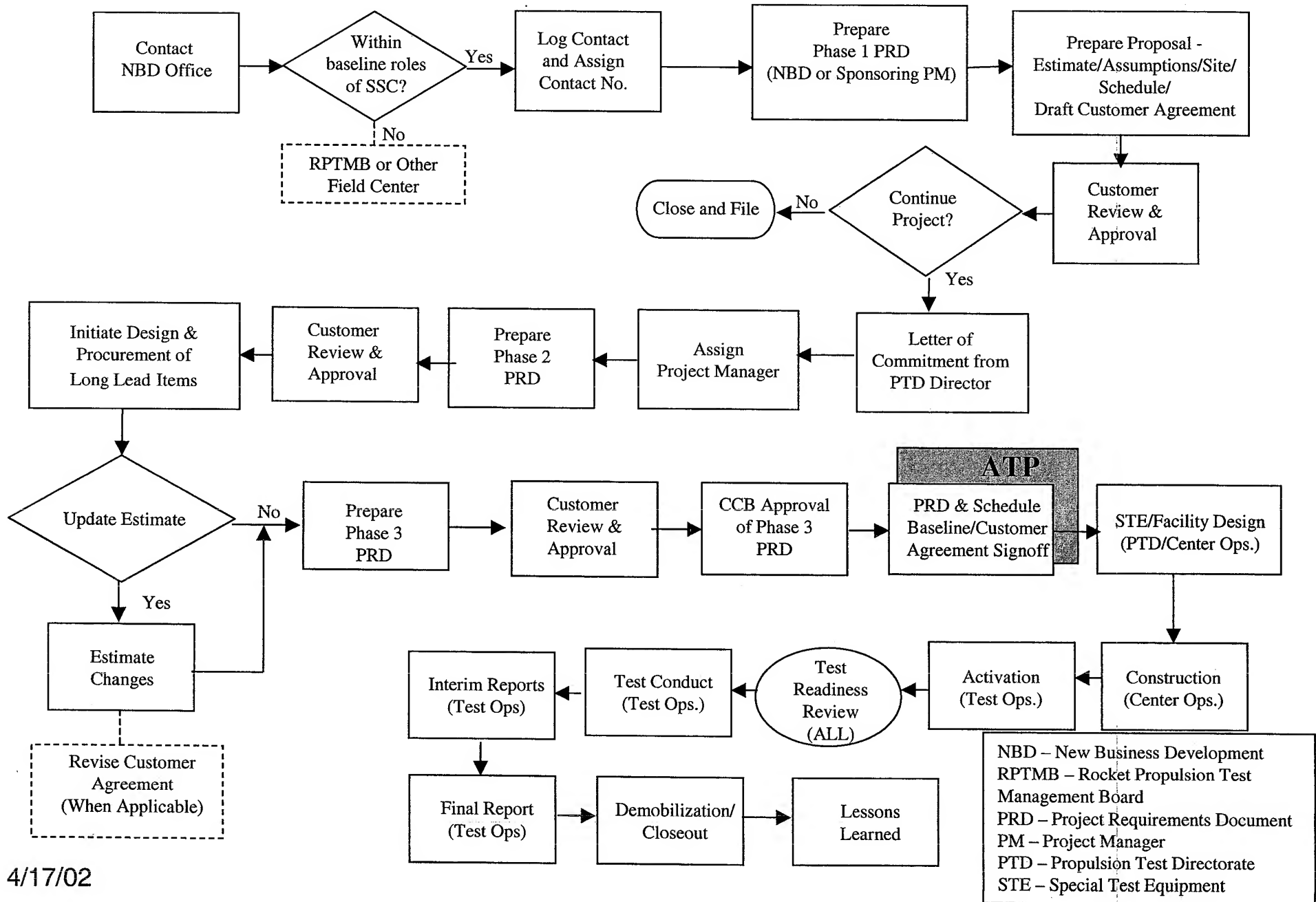
*Stennis Space Center*

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- Ways to Contact
  - Phone
  - E-mail
  - Direct mail
  - Others
  
- Individuals
  - In your hand-out material
  - Usually New Business Development Office or RPTMB
  - Organization charts
  - Web base: Stennis Space Center



# Doing Propulsion Business w/ SSC



# Project X Status (PM)

## FY02 Cost Status

(\$ in Thousands)

|            | Oct | Nov | Dec | Jan | Feb   | Mar | Apr | May | Jun   | Jul   | Aug   | Sep   | EAC   |
|------------|-----|-----|-----|-----|-------|-----|-----|-----|-------|-------|-------|-------|-------|
| TOTAL PLAN | 218 | 475 | 726 | 861 | 1,084 | 726 | 817 | 908 | 1,024 | 1,140 | 1,256 | 1,511 | 1,511 |
| ACTUAL     | 218 | 475 | 726 | 861 | 1,084 | 0   | 0   | 0   | 0     | 0     | 0     | 0     |       |
| DELTA      | 0   | 0   | 0   | 0   | 0     | 0   | 0   | 0   | 0     | 0     | 0     | 0     |       |

### Overview

G Technical –

G Schedule –

G Costs –

### Variance

### Status

### Issues/Actions

# Project X Schedule

| WBS | TASK            | 2001 |   |   | 2002 |   |   |   |   |   |   |   |   |   |   |   | Schedule-to-Date |        | Budget (\$K) |       |         | Index |
|-----|-----------------|------|---|---|------|---|---|---|---|---|---|---|---|---|---|---|------------------|--------|--------------|-------|---------|-------|
|     |                 | O    | N | D | J    | F | M | A | M | J | J | A | S | O | N | D | Baseline         | Actual | BCWS         | ACWP  | EAC     |       |
| 1.0 | Admin/Infra.    |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 100%             | 100%   |              |       |         | 1.00  |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$73         | \$73  | \$103   | 1.41  |
| 3.0 | STE Design      |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 100%             | 100%   |              |       |         | 1.00  |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$102        | \$102 | \$120   | 1.18  |
| 4.0 | Facility Const. |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 100%             | 95%    |              |       |         | 0.95  |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$0          | \$0   | \$0     | 0     |
| 5.0 | STE Const.      |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 70%              | 70%    |              |       |         | 1.00  |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$460        | \$460 | \$792   | 1.21  |
| 6.0 | Test Ops.       |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 60%              | 60%    |              |       |         | 1.00  |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$373        | \$55  | \$630   | 6.87  |
| 7.0 | Support         |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 30%              | 30%    |              |       |         | 1.00  |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$246        | \$106 | \$770   | 2.18  |
| 8.0 | Logisitics      |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 0%               | 0%     |              |       |         | 0     |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$0          | \$0   | \$490   | 0     |
| 9.0 | Maint.          |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   | 0%               | 0%     |              |       |         | 0     |
|     |                 |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$0          | \$0   | \$21    | 0     |
|     | TOTALS          |      |   |   |      |   |   |   |   |   |   |   |   |   |   |   |                  |        | \$1,254      | \$796 | \$2,571 |       |



PDR



CDR

Baseline

Progress

Notes: BCWS=Budgeted Cost of Work Scheduled (i.e., Plan)  
ACWP=Actual Cost of Work Performed (i.e., Actuals)  
EAC = Estimate at Complete

Formulas:

Schedule index = Current/Plan = 35%/35% = 1.00

Cost index = Actual %Schedule/(ACWP/EAC) = .35/(8/100) = 4.38

Index Stoplight Metrics:

Green -- Index = or >1.0

Yellow -- 0.9<Index<1.0

Red -- Index<0.9

4/17/02

# Project X Wrap-up

## FY02 Financial

**Budget**                    \$1,327K  
**EAC**                        \$1,327K  
**Allocated (PAF)**    \$1,085K  
**Obligated**                \$1,085K  
**Costed**                    \$1,084K

## Project Check List

|                                      |             |               |
|--------------------------------------|-------------|---------------|
| <b>NBDO</b>                          | <b>Plan</b> | <b>Actual</b> |
| Space Act Agreement (SAA)            | n/a         | 12/??/99      |
| Handoff to Project Manager           | n/a         | 8/??/99       |
| <b>PM</b>                            |             |               |
| Team Assignment Memo                 | 8/??/99     | 8/??/99       |
| Project Requirements Document, Rev 0 | 11/??/99    | 11/??/99      |
| TTA or SAA (with EPR)                | n/a         | n/a           |
| Detailed Schedule Baseline           | 01/??/00    | 01/??/00      |
| Detailed PAF/Phasing Plan            | 01/??/00    | 01/??/00      |
| Risk Management Plan                 |             | 12/??/01      |
| <b>CUSTOMER</b>                      |             |               |
| Preliminary Test Plan                | 12/??/01    | 12/??/01      |
| Final Test Plan                      | 04/??/15    | 4/??/15       |
| Instrumentation List                 | 12/??/01    | 12/??/01      |
| Test Article Delivery                | 03/??/01    | 03/??/01      |

| Risk - Mitigation - Corrective Action |      |                                                                    |                                                                   |                                                           |          |
|---------------------------------------|------|--------------------------------------------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------|----------|
|                                       | Item | Risk                                                               | Short Term Mitigation                                             | Long Term Corrective action                               | Actionee |
| Y                                     | 1    | 10" Valve may not function properly after design modifications     | Develop Action Plan to Repair                                     | Rework pipe to fit different valve                        |          |
|                                       | 2    | Test Article may produce static spark during operation             | Grounding fix implemented into design                             | n/a                                                       | n/a      |
| Y                                     | 3    | Propellant pressurization systems do not have redundant capability | Spare parts are maintained and preventative maintenance performed | Redundant systems are being procured                      |          |
|                                       | 4    | Multiple programs at E-1 Complex may create scheule conflicts      | Coordinate schedules and prepare priority ranking strategy        | Multiple shifts working and coordination between programs |          |

TTA – Technical Task Agreement  
 EPR – Estimated Price Report  
 PAF – Project Allocation Form

| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |  | Form Approved<br>OMB No. 0704-0188                                     |  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|------------------------------------------------------------------------|--|
| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p> |  |                                                                        |  |
| 1. REPORT DATE (DD-MM-YYYY)<br>16-04-2002                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |  | 2. REPORT TYPE                                                         |  |
| 3. DATES COVERED (From - To)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |  |                                                                        |  |
| 4. TITLE AND SUBTITLE<br>Stennis Space Center Propulsion Test Customer Day 2002 Presentation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |  | 5a. CONTRACT NUMBER                                                    |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |  | 5b. GRANT NUMBER                                                       |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |  | 5c. PROGRAM ELEMENT NUMBER                                             |  |
| 6. AUTHOR(S)<br>Robert Bruce<br>Gary Taylor<br>Bartt Hevert<br>Shamim Rahman<br>Michael Dawson<br>Stan Gill                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  | 5d. PROJECT NUMBER                                                     |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |  | 5e. TASK NUMBER                                                        |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |  | 5f. WORK UNIT NUMBER                                                   |  |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>Propulsion Test Directorate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |  | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER<br><br>IS-2002-05-2003-SSC |  |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |  | 10. SPONSORING/MONITOR'S ACRONYM(S)                                    |  |
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| 14. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |  |                                                                        |  |